
METAL
PROGRESS

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METAL PROGRESS

ERNEST E. THUM, Editor

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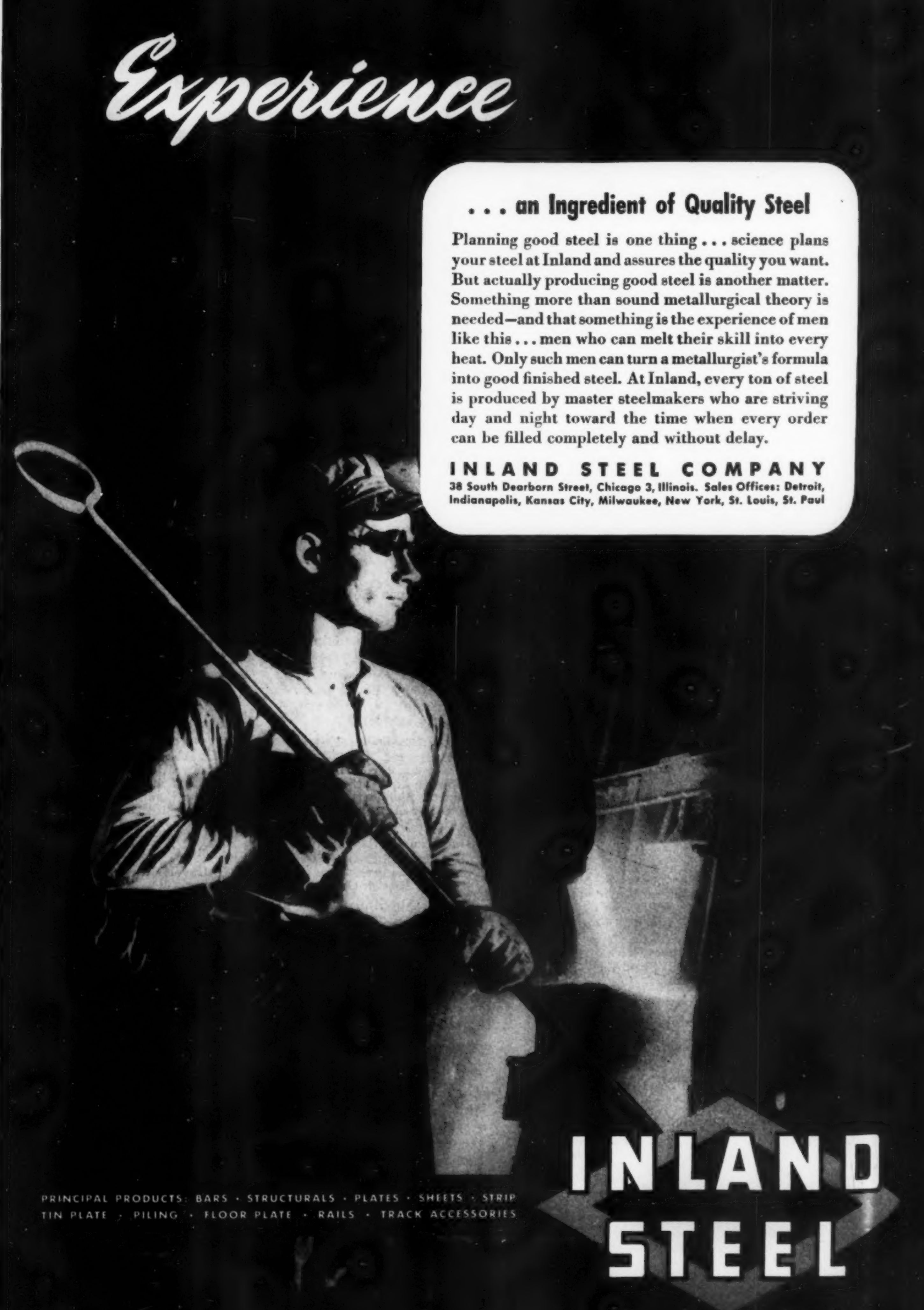
Contents of This Issue

The cover is made from a photograph ($1\frac{1}{2}$ times natural size) of slightly etched charcoal tin plate made by D. H. Rowland of Carnegie-Illinois's research laboratory in Pittsburgh.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INLAND STEEL

A brief outline of what English metallurgists achieved, under stress of war, wherein it appears that they followed along many of the same roads traversed by their American cousins, generally using to the utmost the information gathered more leisurely in prewar years, and pushing new techniques quickly into production that might have lagged slowly otherwise.

WARTIME ADVANCES IN NONFERROUS METALLURGY IN BRITAIN

By BASIL J. S. BARD

Head of the Industrial Research Secretariat of the Federation of British Industries

THE RECORD of achievement of British metallurgy during World War II represents very largely a harvest of specialized development and accelerated methods garnered as a result of long years of patient sowing over wide fields. Inevitably fundamental and long-term research had to be curtailed since 1940 to make way for short-term and applied investigations, and the recorded results of research in the prewar years were heavily drawn upon. In this short review it is not possible to enumerate one tithe of the progress worthy of record and note, or to do more than indicate the general trends at work, and throw into relief the more spectacular advances of British metallurgical research for the war effort. An urgent dynamic stimulus for the development of new alloys, improved processes, and drastic reduction of the time lapse between research discovery and practical application was made manifest — curbed at times by difficulties in obtaining materials, by manpower shortages, by the blackout and the malice of the enemy; shortages of raw materials resulted in their turn in urgent investigations for suitable substitutes.

The liaison between research worker, technician, metallurgist, and production man has been deepened by the over-riding need of attaining practical results in the minimum of time. Many valuable lessons have been learned about organizing the development stage, pilot plant production, and the art of "getting the bugs out of the system". New weapons and war techniques have demanded incessantly metallic alloys with more highly specialized properties — including, particularly, machinability for large-scale production — and combinations of such special properties as workability, conductivity, high strength, and resistance to corrosion.

Radar, rockets, high-speed fighters and heavyweight bombers, jet engines, armored plate for tanks and wheeled vehicles, artillery, protection against weathering in tropical and arctic conditions — all these called for new methods and materials capable of withstanding new and unimagined conditions. Jet propulsion (which applies the principle of Newton's third law of motion that action and reaction are equal and opposite) only became practically realized in the jet engine when the metallurgist was able to provide alloys capable of withstanding the high temperatures and stresses obtaining.

Much industrial research is inevitably devoted to unspectacular day-by-day advances in quality and output, resulting from continuous investigations and speedy application of the results. The Merlin aircraft engine, for instance, which powered the Spitfire and remained in use throughout the war, was doubled in performance between 1939 and 1944 without its weight or size being increased!

Fundamental Researches

Despite the war and the urgency of the times, long-range research at the Cavendish Laboratory at Cambridge, at Oxford, and elsewhere was continued on those most important and fundamental metallurgical questions "Why is a metal?" and "Why is an alloy?". William Hume-Rothery's name comes to mind here as an exemplar of this type of work; Americans know him not only from his published works but from his lectures delivered in the States last autumn. Experimental work into the nature and structure of the metallic state has already yielded significant results.

The crystalline structure of metals, including the mechanics of deformation and the nature of recrystallization, cold and hot working, elasticity, stress and strain effects, shearing strength, and the effect of impurities, have all been examined in terms of fundamental atomic physics. A simple and ingenious technique of model production was developed which simulates the actual conditions obtaining, so far as we can understand them — including not only a genuine cohesive force over the structure as a whole, but also a repulsion between individual "atomic" units!

Copper Alloys

There is no space here to record the production achievements of the British metal industries, nor to restate the obvious. In copper, for instance, vast tonnages of cartridge brass were fabricated into cartridge cases. Bronze, gun metal and high-tensile brass castings formed essential parts of ordnance, aircraft, and transport by sea and land.

Aluminum bronze, containing 10% aluminum with 5% each of iron and nickel, was a greatly favored alloy where exceptionally high strength and resistance to wear and corrosion were required for aircraft and ordnance. This alloy was shown to be capable of being arc welded when using coated electrodes — now a normal industrial practice.

Free-machining copper containing 0.5% of tellurium was one of the vital factors in the development of the magnetron valve, the very heart of radar equipment. Demands were for a material of high electrical conductivity, capable of being machined to exceptionally fine tolerances.

Three other copper alloys whose use was greatly developed were, first, copper-lead for bearings for internal combustion engines and for all kinds of high-duty purposes; this alloy was produced by powder metallurgy, electrolytic and casting methods. Second, chromium-copper for welding electrodes. Third, beryllium-copper for precision parts. Comparable, but cheaper, copper-nickel-manganese alloys are now being developed.

There have been many advances in the technique of melting and casting tin bronzes, including oxidation of the melt to eliminate hydrogen, followed by reduction by phosphorus or a similar deoxidant. W. T. Pell-Walpole, who has been associated with this long-range development, has already presented a review of this notable work in *Metal Progress* for last December.

Research on the corrosion of condenser tubes and on the development of new tube alloys has been in progress in Britain for many years, resulting in two important developments. The first is the improvement of the well-known 70-30 cupronickel by the deliberate addition of 0.5% of iron; this has been widely used in the main condensers of many naval and merchant ships. The second is an aluminum brass (76-22-2) containing a small amount of arsenic, which is used more extensively by the merchant navy — yet also to a considerable extent by the Admiralty, particularly for high-temperature heat exchangers. As Mr. Churchill said in Britain's House of Commons, an answer had at last been found for "condenseritis", and "our ships seem to steam on forever".

One of the major metallurgical advances of the war years was the development of the "Nimonic" series of nickel-chromium alloys with adequate strength to withstand the onerous operating conditions of gas turbine units used in jet propulsion. These also can be fabricated by forging and machining into complicated finished shapes. "Nimonic 80", with its exceptionally high creep resistance, is now the standard material for the rotor blades of all designs of British jet engines.

Other Developments in Alloys

Interesting developments have occurred in nickel-containing steels, nickel-containing permanent magnets and special nickel alloys for welding. New monel alloys were devised, including a special K monel for cold headed bolts, and monel castings for superheated steam fittings and other equipment where resistance to corrosion at high temperatures combined with good founding characteristics is required. Considerable headway has also been made in precision casting techniques for production of nickel alloy parts of all types.

Developments in the use of tin have been conditioned by the shortage which arose from the Japanese invasion of Far-Eastern mining regions. Inventiveness has therefore been largely concerned with processes to achieve maximum possible effi-

ciency in the use of the available metal. Apart from this a saving was secured by austerity methods, since tin is a metal for which it is fundamentally difficult to find a real substitute. An outstanding feature has been electrotinning, now widely used here as well as in America. Industrial processes are based on new plating solutions which produce compact coatings whose thickness can be reliably controlled by fully established techniques. Electrodeposited tin-zinc alloys, in particular, give more protection to steel, especially under salt spray and very humid conditions. The old tin-copper alloy known as speculum has been electrodeposited as a hard, brilliant deposit, highly resistant to tarnish, having wide applications. Its potentialities for peacetime uses for such purposes as cutlery and plate are believed to be considerable.

Important improvements in techniques in such fields as soldering and dip-tinning of steel and cast iron resulted from specialized research. In the field of packaging, a notable advance was the development of a simple dip, forming a film which greatly increased the resistance of ordinary hot dipped tin plate to rusting and to sulphide staining.

An outstanding development since 1939 has been the widespread use by British manufacturers of zinc alloy die castings for the speedy production of intricate shapes to close dimensional limits. This has, indeed, kept pace with a similar movement in America. Furthermore, high purity zinc alloys are insisted upon, since — as is well known — they result in castings with high stability and good corrosion resistance. Advances were also made in the industrial control of the casting processes.

There have been interesting advances in the use of zinc for protection coatings, experience showing that hot-dip galvanizing is unrivaled for the long-term protection of iron and steel. Such advances include prefluxing, thermostatic control of the molten zinc, and improved methods of heating the galvanizing bath.

Apart from extension of their use as primers for iron and steel work, zinc metal pigmented paints have been used for the protection of ship drinking water tanks and as welding primers.

New Fields of Metallurgy

Aluminum reduction, being largely dependent on plentiful supplies of cheap electric power, was inevitably lagging in Britain in comparison to Canada, but methods of recovery of secondary metal from crashed and obsolete aircraft were devised and developed. Fabrication and foundry capability and technique were alike greatly enlarged. Massive forging plant has opened up entirely new fields — for example, the 12,000-ton forging press and very large drop hammers used for propeller blades and engine crank cases have vast potentialities for high-strength forgings and for the engineering industries.

Welding, fabrication and riveting have all been greatly improved — notably, a unique system of blind riveting where one side of the joint is inaccessible; precision spot welding, even for portions of combat aircraft that carry high stress; pressure welding at temperatures of some 200° below the melting point of the material; a mass production brazing process, and the use of plastic adhesives to join metal to metal.

There has furthermore been an appreciable increase in the general level of mechanical properties of aluminum alloys and their reliability and uniformity.

Britain was the first country in which magnesium was extracted from sea water and dolomite, and there was eight-fold expansion in magnesium production during the war years. A British firm led in the design, building and operation of the Basic Magnesium 50,000-ton plant near Boulder Dam, Nev. Very large factory extensions were also built in Britain for fabricating the necessary magnesium alloy, primarily for aircraft and secondly for incendiary bomb casings. There have been great improvements in resistance to corrosion, in mechanical properties, and in useful characteristics of magnesium alloys as regards microporosity, castability and ease of working.

Two important developments in magnesium have been *(a)* the evolution of new alloys containing zirconium; proof stress in the cast and extruded condition are of the order of 22,500 and 45,000 psi. respectively; ultimate strength 36,000 and 50,000 psi., and 7 and 10% elongation, respectively. *(b)* Corrodibility has been brought under control by a combination of the use of material of suitable purity and the evolution and proper application of improved paint schemes.

Electroplating

Protective Coatings — Brass plating was used for the protection of steel cartridge cases for medium caliber guns. This enabled fired cases to be reconditioned by annealing the mouth without spoiling the coating.

Much research has been carried out on chromium electroplates, including a scheme for depositing chromium without cracks in a sufficiently soft state to be machinable with a pointed tool. On the other side, hard chromium facings gave tools vastly increased lives. *(Cont. on page 460)*

When numerous propellers develop quench cracks in production from 20 heats of steel, indistinguishable metallurgically from previous heats that gave no such trouble, and the trouble started immediately after the prepared atmosphere generator had been cleaned and repaired (production routine unchanged otherwise), it was logical to look for the cause in the composition of the atmosphere in which the propellers were heated — and to find the trouble there.

HIGH-HYDROGEN ATMOSPHERE INTENSIFIES QUENCH CRACKING TENDENCY

By C. A LIEDHOLM

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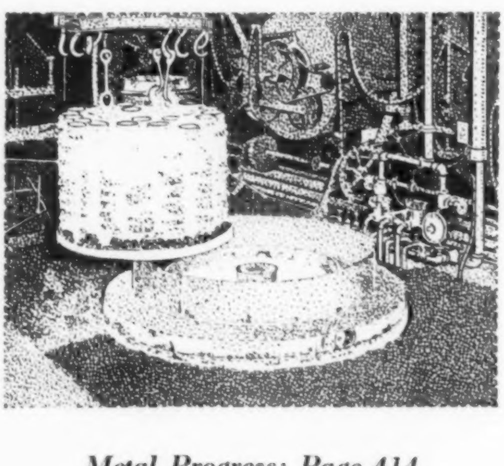
AN EPIDEMIC of quench cracking is usually a costly event, whose possible occurrence no heat treating shop can afford to discount. Frequently, the economic losses mount faster than the casualties from the disease, so it is extremely important to diagnose the symptoms promptly and correctly.

The metallurgist confronted by the harassing experience of a major quench cracking epidemic may find the solution to his troubles in such factors as excessively dirty or coarse-grained steel, extremely high hardenability, poorly annealed structure, excessive residual stresses, excessively rapid heating through the black heat range (causing thermal bursts which may be mistaken for quench cracks by the operating personnel), too high a hardening temperature, too drastic or nonuniform quenching, surface notches, deep stamp marks, or faulty design.

However, there are times when quench cracking troubles arise despite the absence of any of the causes enumerated above, or when no recent change in any of them can be discovered. The *furnace atmosphere* should then be included among the suspected causes of the epidemic, especially when the atmosphere has a tendency to carburize the steel and contains a substantial proportion of hydrogen.



That hydrogen is one of the likely causes of quench cracking would be suspected by anyone who is even slightly familiar with the effects of this gas upon metals. It is, therefore, somewhat of a surprise that among the numerous articles published in recent years concerning the effect of hydrogen upon steel, little if anything has been written about quench cracking. The only author who has even mentioned this subject, as far as this writer could find, is Carl A. Zapffe, who in an article entitled "Sources of Hydrogen in Steel and Means for Its Elimination" in *Metal Progress* for March 1943 (page 401) makes this remark: "Perhaps even quenching in water is dangerous for certain sensitive steels."

It is now my intention to describe briefly the laboratory tests and confirming evidence from production heat treating experience which have led

me to the conclusion that the hydrogen content of a reducing furnace atmosphere is a tremendously potent factor in quench cracking — the more so the higher the carbon content of the steel or carbon pressure of the atmosphere, or the greater the severity of the quench. The laboratory experiments have resulted in the development of a test method which still is of a preliminary nature, but nevertheless has yielded results that have clarified formerly obscure relationships among quench cracking, carbon content, atmosphere, and quench delay. The necessary background information concerning the product of manufacture, the quenching method, and the materials involved is as follows:

The parts manufactured are hollow steel propeller blades which are simultaneously die straightened and quenched at 1680° F. in "Meehanite" dies. The thin sections in the outboard part of the blades harden readily from the chilling effect of the cold dies with which they are gripped, whereas water is forced externally over the heavy shank sections furthest inboard. Some delay is inherent in the operation while the blades are transferred from the furnace and positioned in the die. Close contact with the latter is insured through nitrogen at about 1000 psi. injected through the shank into the hollow blade.*

The formerly used material is designated as CPS 4524 which is similar to S.A.E. 4330 although its alloy content is higher. CPS 4504 propeller steel (similar to S.A.E. 4320 although with higher alloy content) was recently adopted and has now been in use for over a year.

It is hoped that the two preceding paragraphs contain enough information to serve as a background for the description of the quench crack sensitivity test which will now be attempted.

Sensitivity Test

The test pieces referred to as Type 1 and Type 2, and illustrated in Fig. 1, were designed so as to promote quench cracking by a stress-raising notch. To avoid decarburization while heating in hydrogen, machined specimens are copper plated 0.0005 in. thick, and subsequently annealed at 1110° F. to release the hydrogen absorbed during plating. It was hoped that, when the test pieces were drastically quenched from a laboratory furnace, they would be equally as sensitive to cracking as the shanks of propeller blades. Since experience in production had indicated that propeller blades quenched with a short delay were most likely to crack, it was highly desirable to verify this by some experiments.

The atmosphere usually employed in the laboratory furnaces was of the rich "Monogas" type with approximately 8.5% hydrogen and a dew point of 14° F. The same atmosphere was employed in a nearby experimental production shop.† The first experiments were quite discouraging in that the specimens refused to crack, even when the most drastic quench was employed!

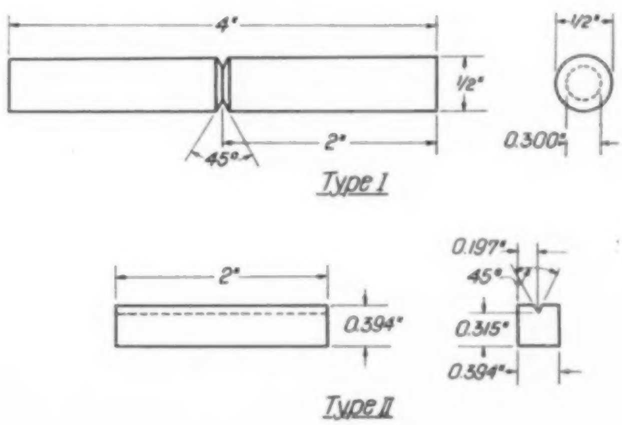


Fig. 1 — Dimensions of Test Specimens to Determine Crack Sensitivity

At this point, the thought occurred that if hydrogen was largely to blame for underbead weld cracks, shatter cracks in steel rails, flakes or internal rifts in alloy steel sections, why would it not help to produce quenching cracks? Heating the specimens in 100% hydrogen at 1700° F. prior to quenching proved the correctness of this assumption. Without exception, specimens of Type 1, machined from CPS 4524 propeller blade plate stock, hardened in water without a quench delay, cracked longitudinally within 24 hr.

Subsequently, small groups of specimens from the same heats of CPS 4524 material were quenched after various air cooling periods or quench delays, in order to verify the conclusion reached by trial-and-error production experiments that quench cracking could be prevented through an extended quench delay. Happily, the result obtained by the two methods showed a useful similarity. The plant experiments had indicated that a 3-min. quench delay was required to eliminate cracking of blades of a certain design which had given the greatest amount of trouble. The Type 1 laboratory tests from a heat with the maxi-

*C. A. Liedholm, "Diagram of Transformation During Continuous Cooling of Steel (A Necessary Guide for Propeller Blade Heat Treatment)", *Metal Progress*, November 1944, p. 1097.

C. A. Liedholm, "Experimental Studies of Continuous Cooling Transformations", *Transactions*, V. 38, 1947, p. 180-208.

†C. A. Liedholm, "Atmosphere Calibration for Heat Treating Airplane Propellers", *Metal Progress*, April 1946, p. 744.

mum specified carbon content remained intact after a quench delay of the same duration, but cracked when given a 150-sec. quench delay, thereby establishing a fair correlation between the laboratory test and the production experience with the most troublesome blade.

Trial-and-error production heat treating experiments had indicated that the more recently adopted CPS 4504 propeller material could be quenched safely with a 60-sec. delay. Heats with the maximum and minimum carbon contents corresponding to that specification were tested using specimens of Type 1. Heat No. 101, carbon content 0.22%, showed cracks after a quench delay of 45 sec. (but none after 60), whereas heat No. 98, with a carbon content of 0.16%, would not crack even when quenched directly in water from 1700° F. Here, again, the results of the trial-and-error experiments on a production scale had been verified.

On a tentative basis, the test which has just been described has been included among the routine investigations depended upon as a basis for specified quench delay tolerances. Since the thoughtful reader is expected to wonder what kind of structures might result from such long quench delays, it is in order to add that other tests (described in *Transactions* ⊕, V. 38, 1947, p. 180-208) are employed to insure that the fatigue and tensile strengths are not unduly impaired. Before final approval, the experimentally determined quench delay is further verified by testing the hardness of propeller blade sections taken throughout the length of the blade. Panels of such test pieces are shown in Fig. 2. It has been established in this manner that blades made from CPS 4524 material (except for one design) could be quenched safely with a 90-sec. delay under normal operating conditions. Fortunately, the exception to the rule is a very large and heavy propeller blade which cools so slowly that no excessive transformation to soft products occurs during the 3-min. quench delay.

The laboratory results obtained by the time this article was written, have been listed in Table I. Notations for each experimental quench delay are a fraction whose numerator denotes the number of cracked specimens and the denominator gives the total number of specimens for each treatment and steel. In the first line, first column, for example, 3/3 means that 3 specimens cracked out of 3 specimens tested. Under ROCKWELL MIN./MAX. the minimum hardness associated with the longest experimental quench delay is shown as the numerator, and the maximum as-quenched hardness as the denominator. Specimens of Type 1 were employed to test raw plate stock, whereas Type 2 was used to sample the manufactured product because larger specimens could not be obtained from some propeller blades. The two specimens appeared to give fully comparable results.

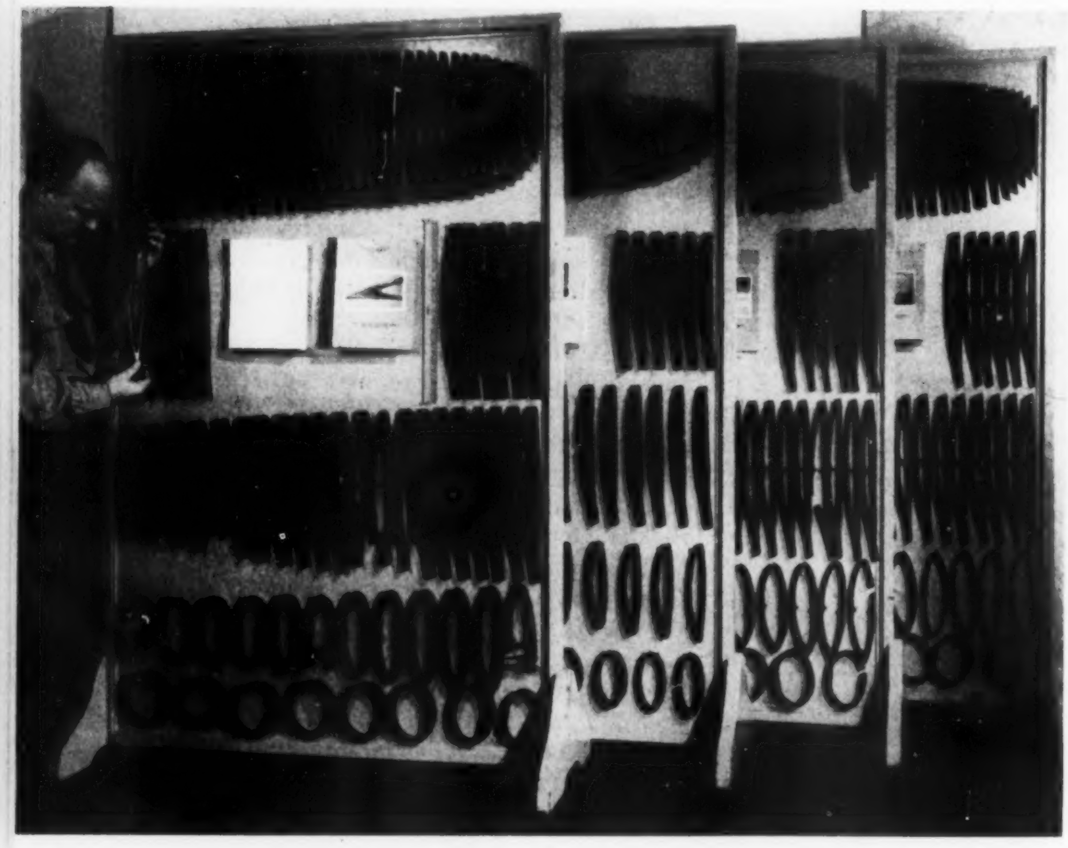


Fig. 2 — Panels Showing How Sample Propellers Are Cut Into Small Sections for Hardness Tests and Inspection by Internal Magnaflux, Zyglo, and Macroetch

Hydrogen the Culprit?

From the data reported above, the temptation to indulge in speculation arises irresistibly strong!

First, however, sober reflection suggests that perhaps the correlation between plant and labora-

Table I — Quench Crack Sensitivity Tests

Material	% C	Specimen	Quench Delay, Sec.										Rockwell Min./Max.	Atmosphere
			0	15	30	45	60	90	105	120	150	180		
CPS 4524	0.33	Type 1	3/3	—	—	3/3	—	—	—	4/4	—	0/3	—	H_2
CPS 4524	0.32	2	—	—	2/2	—	2/2	2/2	1/1	1/1	1/1	0/1	—	H_2
CPS 4524	0.32	2	—	—	2/2	—	2/2	1/2	2/2	—	2/2	0/2	—	H_2
CPS 4524	0.32	2	—	—	2/2	—	2/2	2/2	1/1	0/2	0/2	—	—	H_2
CPS 4524	0.31	2	—	—	2/2	—	2/2	1/2	1/1	1/2	0/2	—	—	H_2
	0.31	2	—	—	2/2	—	2/2	2/2	1/1	1/2	0/2	—	—	H_2
CPS 4524	0.30	2	—	—	1/2	—	2/2	1/2	1/2	0/2	0/2	—	—	H_2
CPS 4524	0.27	1	—	—	2/2	—	2/2	1/2	—	0/2	—	—	C-51/52	H_2
CPS 4504	0.22	1	—	—	1/2	1/2	0/2	0/2	—	—	—	—	—	H_2
CPS 4504	0.16	1	0/1	0/1	0/2	0/2	0/2	0/2	—	—	—	—	C-43/44	H_2
CPS 4524*	0.33	1	0/4	—	—	0/4	—	—	—	0/4	—	0/2	—	Monogas

*Same heat as shown in first line.

tory results was a matter of mere luck. *Hydrogen alone* has been rejected as a cause for underbead weld cracks, flakes, and shatter cracks by several authorities, it being assumed that transformation and thermal or other stresses are essential accessories to its crimes. Undoubtedly, quench cracking of propeller blades depends also to a large extent upon the distribution of thermal stresses during the quenching operation, and these vary with the design of the blade. But the destructive forces which cause propeller blades heated in Monogas to crack during quenching apparently are matched by those arising during the laboratory quenching of notched specimens only if the latter have first been loaded with hydrogen. Inherently, high hydrogen content may be a factor to reckon with in the large blades requiring the quench delay of maximum length, since the huge rib-rolled plates from which these blades are manufactured have shown a tendency toward flaking.

From Table I it is noted that the higher the carbon content, the longer is the quench delay required to suppress cracking. In CPS 4524, 180 sec. is needed when carbon is 0.33%, 60 sec. when carbon is 0.22%. On the basis of these tests in 100% hydrogen, the quench crack sensitivity of various materials can be readily compared.

The question immediately presents itself, whether the beforementioned difference among the steels is due to the gradual escape of hydrogen during the air cooling period (quench delay) or to a difference in the progress of transformation during cooling. An interesting parallel is afforded by a study of microscopic cracks in steel, reported in *Transactions* A.S.S.T. for April 1934 (V. 32), by E. S. Davenport, E. L. Roff, and E. C. Bain. Speaking about microcracks, these authors made the following statement, worthy of repetition:

> "The presence, in suitable amount, of a well-distributed soft constituent (such as fine pearlite resulting from low quenching rate, acicular troostite from incomplete transformation at elevated constant temperatures, or possibly retained austenite in alloy steel) eliminates the microcracks in the martensite. At the very least 25% of the softer constituent seems to be necessary; in the case of a coarse austenitic grain size, cracks may form in spite of the presence of the softer constituent."

Against the background of this quotation, it is interesting to note that welds of high harden-

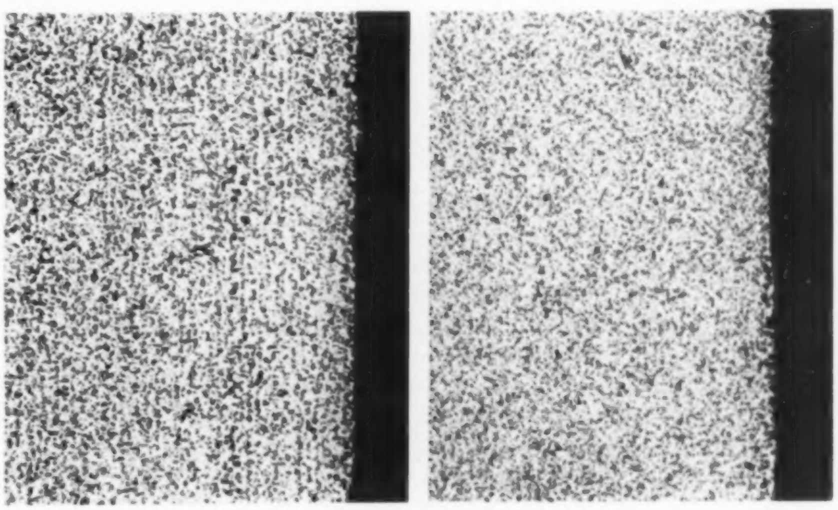
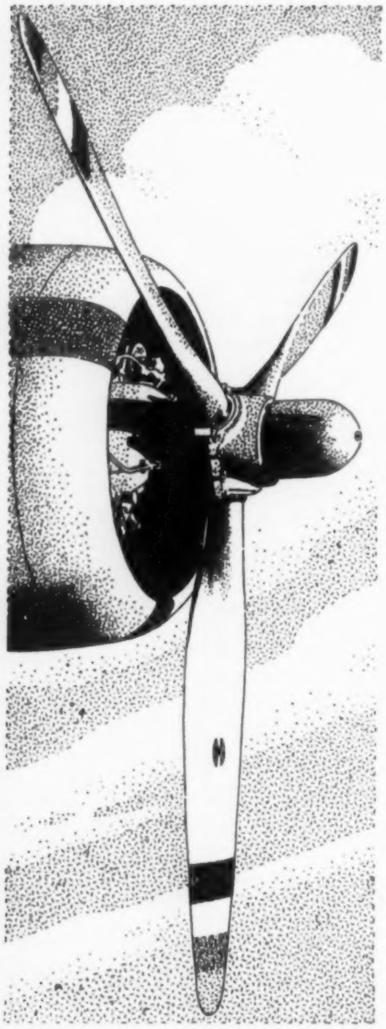


Fig. 3 — Typical Micros at Edge of Camber and Thrust Plates Show Freedom From Carburization and Decarburization



ability steel have been found to contain transformation cracks in the presence of as much as 50% ferrite; but welds in the same steel having a similar structure develop no transformation cracks when the remaining austenite is postheated long enough to let some of the imprisoned hydrogen escape gradually instead of staging the "large-scale jail break" which is initiated by the martensite transformation in steel not postheated. One feels tempted to ask if the advantages of austempering might not in part be due to the escape of hydrogen during isothermal transformation (at elevated constant temperature).

Again, one might wonder if even the 0.16% carbon heat shown in the next to bottom line in Table I could have been made to crack during quenching if heated to a high enough temperature. If it could, the cracks might partly be due to the increased absorption of hydrogen.

And lastly, does the greater sensitivity of these high carbon steels upon heating in hydrogen point toward methane as a factor in quench cracking?

Further work has been planned to investigate these variables.

Production Observations

Rotary electric pit furnaces, with 10 blade stations per unit, are employed in regular production hardening at Curtiss-Wright Corp. Propeller Division. In accordance with the required heating cycle, the loading and unloading doors are opened every 6th to 10th min., while one blade is withdrawn and another charged. Therefore, the atmosphere must be rich enough to retain a reducing condition in spite of the relatively frequent inrush of air in considerable quantity — the only other alternative being a flow of prepared atmosphere at an enormous rate. The atmosphere in actual use is of that so-called endothermic type which the American Gas Association has designated as No. 301,★ and assigned the following nominal composition:

N_2	CO	CO_2	H_2	CH_4	Dew Point
45.1%	19.6%	0.4%	34.6%	0.3%	50° F.

Fairly wide variations from this composition are quite common, especially when the atmosphere is prepared from city gas.

An epidemic of quenching cracks whose demonstrated cause lay in the variations of the composition of this atmosphere will now be briefly described.

A fairly complete study of the atmosphere composition and its effect on the steel had been completed over a month before CPS 4524 material commenced to crack during quenching. The atmosphere was produced through the reaction at 1900° F. of approximately equal volumes of air and city gas, supplied to each furnace at the rate of about one volume change each hour. To prevent decarburization, 25 cu.ft. of natural propane gas was added to each 1000 cu.ft. of the prepared atmosphere.

Under these conditions the individual gas constituents were not in equilibrium with each other; hence, attempts to calculate the carbon pressure of that atmosphere from its composition by the method described by E. G. de Coriolis, O. E. Cullen, and Jack Huebler, *Transactions* ⊕, V. 38, 1947, p. 659 to 685, gave results which varied widely depending upon the reaction under consideration. However, metallographic studies indicated neither carburization above about 0.30% C, nor decarburization, Fig. 3 being typical of the results we obtained.

It was obvious that the propane addition compensated for the air which rushed in during the frequent loading and unloading periods.

Shortly after the completion of this atmospheric survey, the generator was shut down for overhauling. Leaks had developed in the reaction tubes, and, in addition, the flow rate had dropped because tubes were clogged. It was when the generator was returned to service that quench cracking began. A long casualty list of spoiled articles testifies to the seriousness of the trouble which descended upon us.

It is characteristic in situations of this kind that factors with no previous record for making trouble should be included among suspected causes. In order to get this matter under quick control, four principal corrective measures were immediately applied:

★C. C. Eeles and M. E. Shriner, "Prepared Atmospheres", American Gas Association Information Letter No. 9.

1. The propane was shut off (even the tank installation was removed).

2. The quenching dies were reworked *(a)* to insure that the blades were as free as possible to contract and *(b)* to provide more uniform flow of quench water.

3. The quench water was heated to 80° F.

4. Increased care was exercised to eliminate notches from the shank surfaces.

However, cracking continued much as before, until the seemingly far-fetched suggestion was made (and adopted) that the atmosphere flow be reduced to approximately the same rate as had been delivered by the somewhat clogged generator some time before its shutdown. The trouble immediately disappeared!

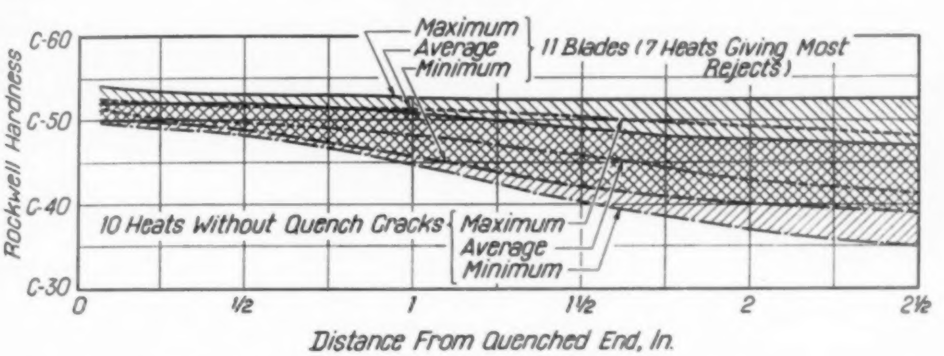


Fig. 4 — Hardenability Bands (Maximum, Minimum and Average) of Jominy Tests on Heats With Most Spoilage and Trouble-Free Heats

The *post factum* theory was proposed that this entire costly incident might have been due to the manufacture of certain abnormally crack-sensitive heats of steel. A review of the spoilage record appeared to bear out this hypothesis, at least in part, since seven of the 20 heats involved had contributed 76½% of the spoiled articles. The spoilage, in percentage of blades made from each heat, varied between 10.2 and 31.4%.

For a datum, a random selection was then made of 10 other heats, all of which had passed through the quenching operation during the trouble period without spoilage. Jominy tests were prepared and drillings secured for analysis from 11 blades made from the worst seven and these 10 crack-free heats. The Jominy and calculated hardenabilities of these materials were compared, but (although the troublesome heats showed somewhat higher maximum, average, and minimum hardenabilities) the differences were considered too insignificant to form the basis of a successful argument. The hardenability data have been summarized graphically in Fig. 4. However, nine of the 11 analyses for carbon of the worst seven heats showed between 0.32 and 0.34% C, whereas nine of the 10 crack-free heats showed a maximum carbon content of 0.31%. This is a small variation, no greater than had always occurred and continued to exist after the disappearance of quench cracks.

Returning to Table I, and keeping the fact in mind that the blades at the time of trouble were quenched with a delay of 120 sec., one finds that of six heats with 0.31 to 0.33% C, five developed quenching cracks upon heating in hydrogen followed by quenching with a 120-sec. delay. Note in particular that the most sensitive heat, shown in the first and the last lines in the table, altogether refused to crack during quenching after heating in Monogas, and that no CPS 4524 propeller blades have been known to crack upon heating in that atmosphere even though this quench delay subsequently was shortened to 90 sec. The theory that the spoiled blades had picked up carbon was not substantiated by metallographic examination. Had carburization occurred, the carbon content of the steel could hardly have been so critical a factor, but all heats could have been expected to crack with less extreme variations in frequency.

The explanation remains that quenching cracks were eliminated by decreasing the atmosphere flow, and this decreased the hydrogen absorbed by the steel, probably because the furnace atmosphere had become less reducing. It would be difficult to account for and reconcile all of these observations except on the basis of the proposed explanation.

This contribution is a preliminary and partial discussion of a problem involving several variables that require much further investigation. The discussion is concerned only with steel of high hardenability which was drastically quenched, and hence the conclusions may not apply with equal force when a different set of variables is involved — for instance, when the steel is quenched in oil instead of water, or when the hardenability of the material is low.

The expensive experience and our study of its causes is described at such length not only to place something on the record which may help solve some future trouble in other plants, but also to invite accounts of experiences elsewhere which may have some bearing on the serious practical problem of quench cracking.

An epidemic of broken tools used in the manufacture of small arms ammunition led to doubts as to the efficacy of magnetic particle inspection, which had shown negative results when testing these tools. It was found that hardened and ground tools, apparently crack-free, developed tiny surface cracks in the chromium plating bath, and these cracks were later undiscovered. Change in the equipment and technique of magnetic inspection, together with draws at 350° F. to relieve internal stresses, brought rejects down from around 50% to 0.5%.

MAGNETIC PARTICLE INSPECTION OF CHROMIUM-PLATED TOOLS

By M. H. MUELLER and W. E. YEAST

Members ⊕; formerly metallurgists with Des Moines Ordnance Plant

DURING the war, in a period of 3½ years, we used magnetic particle inspection for the detection of defects in 5,300,000 tools and dies for small arms ammunition. From time to time, we encountered problems for which we generally found a satisfactory answer. However, the use of this method with tools and dies which have a hard-chromium plate presented a great obstacle at first in the form of undiscovered defects. Many times a flash plating of chromium or cadmium will provide a more desirable background and aid in the visibility of indications, but this is not true with heavier deposits of hard chromium.

It is always advantageous to profit from the errors and experiences of others rather than expend work and money to find out the hard way: too often the results are negative. Unless an inspector is thoroughly familiar with the technique and limitations of magnetic particle testing and the mechanics of hard-chromium plating, he is likely to be baffled since the latter serves as a giant portcullis to the entire inspection. There are five specific reasons for chromium plating:

1. Hard chromium has a comparatively dense structure and does not pick up particles, thus greatly reduces friction.
2. A dimension can be easily and accurately increased.
3. It is possible to repair and salvage tools and dies that have been used by simply grinding off the damaged or worn surfaces and rebuilding with chromium.
4. Hard-chromium plating may produce a wear resistant surface of uniform hardness, which is greatly desired on parts subjected to drawing or frictional operations.
5. A plated tool can be used to full life, stripped, replated, and put into service numerous times without requiring further work, as long as the supporting material has not been damaged.

Our primary concern was with the production of tools, dies, jigs, fixtures, and gages used to manufacture caliber .30 and caliber .50 ammunition. Some of these are subjected to loads up to 35 tons and great stresses, while others operate under high frictional and heat conditions. (A survey of surface temperatures revealed common working temperatures of 125 to 180° F.) In the manufacture of tools, it was the policy to maintain rigid metallurgical control, limiting fabrication to the finer grades of tool and die steels, hardened and drawn to a high but reasonable Rockwell range.

As is stated by James P. Gill in the ⊕ publication "Modern Steels": "There are two important physical properties of magnetic steels that chiefly determine their adaptability. First, the amount of magnetism which the steel is capable of retaining immediately after the magnetizing force is withdrawn. The second might be termed the tenacity with which the steel holds the magnetism. In other words, can the magnet be knocked around, and still retain its magnetism?"

Such residual magnetism is fairly uniform and does not fluctuate a great deal in the various

types of toolsteels, while the coercive force (the force necessary to wipe out a given amount of magnetism) has a wide range of variation and can never be depended upon from one member to another in this vast family. With few exceptions, hardened tool and die steels are ideal for residual magnetic particle inspection by either the "wet" or "dry" residual method.*

Magnetic particle inspection has proven itself very beneficial to ammunition makers: First, defective material produced defective parts, increased lost man-hours and boosted the final cost of the product. Second, defective parts presented definite safety hazards to operators and equipment. Third, defective parts decreased output by machine down-time.

From time to time, we experienced high tool

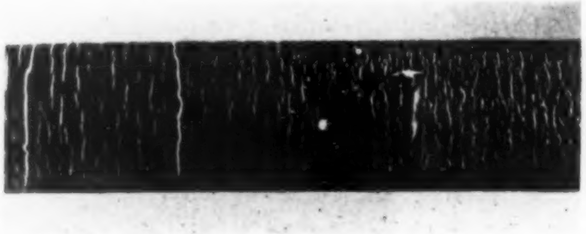


Fig. 1 — Indications (Slightly Enlarged) on Defective Tool After Removing Chromium Plate

mortality in production, due to excess breakage. When these failures were returned to the laboratory for check, we discovered they had been chromium plated. The base metal below the chromium surface was also slightly discolored on the fractures. The same parts had been magnetically inspected before and after plating, following the final grind or prior to delivery to production. The answer to all three inspections was negative, and the parts were believed to be free from defects.

In order to analyze these specimens accurately, they were stripped, again magnetically inspected using fluorescent powders and ultraviolet lamps — a method providing greater visual sensitivity. Each part treated in this manner showed a series of fractures comparable to tiny grinding cracks running circumferentially on the body. This is shown in Fig. 1.

At this point several unanswered questions confronted us:

1. If the parts were properly magnetized and inspected, before delivery to production, why were we unable to detect these defects?

2. Why did the discontinuities show discolored metal, giving evidence of fracture preceding the application of chromium?

3. Why had these fractures not gone through the chromium-plated surface, with the exception of those that had broken in the machines?

By further testing similar specimens, using rectified a.c. continuous and d.c. continuous methods, faint feather-edged buildups due to subsurface interferences were produced. The d.c. continuous method seemed to have greater power of penetration, affording maximum flux density. However, the indication would not be sufficient to use as a basis for rejection, although the fractures were extensive enough to cause failure in the shop and reduced the body strength 75%.

Microscopic observation of the chromium surfaces showed minute fractures (Fig. 2); however, they were very unlike the circumferential grinding patterns.

From good authority, we learned that it is natural for hard-chromium plating to possess both surface cracks and porosities below the surface. In an article written by T. G. Coyle, of United Chromium in the 1944 edition of American Electroplaters' Society *Proceedings*, he states: "We know that chromium, as deposited, is generally, though not always, under great stress and usually contains cracks of microscopic size. Open cracks are often found in the surface of the plate; but there also are sealed-over cracks below the surfaces. From almost the very initiation of deposition, a stress is created in the deposit. As the plate builds up in thickness, it appears that this stress increases until it reaches the ultimate strength of the chromium deposit, which then fractures relieving the stress and leaving fine cracks. These very fine cracks heal over as the plating continues, and the stress builds up again to the breaking point and new cracks form which, in turn, heal over. This goes on throughout the whole plating time, with outer surface frequently showing open cracks, and covering over at varying

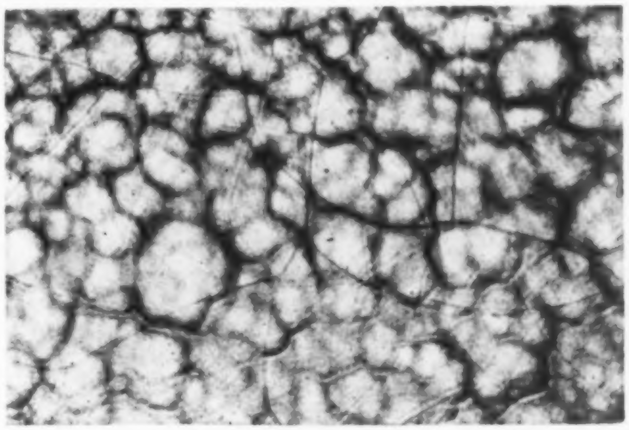


Fig. 2 — Chromium-Plated Tool Flat That Showed Cracks Under Microscopic Examination (250 ×)

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*See "Principles of Magnaflux Inspection" by F. B. Doane.

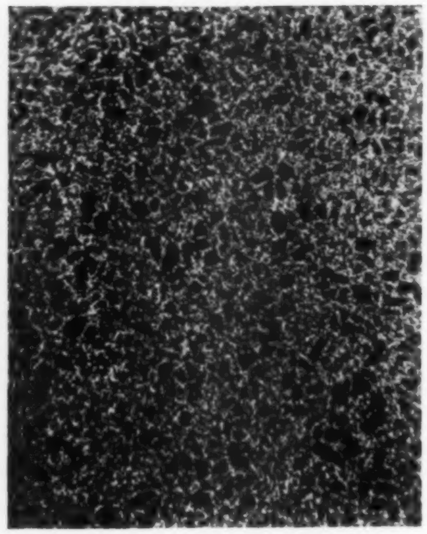


Fig. 3 — Zyglo (Photographed in Ultraviolet Light) Indicates Badly Cracked Chromium Plate (10 ×)

depths below the surfaces, healed-over cracks."

In an effort to verify these statements of Mr. Coyle's, we took some tools which had sizable crack-free areas, or what appeared (visually) to be crack-free, and subjected these specimens to "Zyglo", a fluorescent penetrant used in testing nonmagnetic materials for surface defects. Figure 3 is a micrograph at 10 × of this test, photographed by ultraviolet illumination.

From the general information available it was assumed that this surface condition was normal and had no relation to the fractures in the base metal. Next several unworked tools were selected and followed through the fabrication stages, inspecting after each operation. In this way some of the outstanding causes for the cracking of chromium-plated tools were discovered, as will be discussed in later paragraphs. In addition, a fairly satisfactory conclusion as to the effect of chromium plate on magnetic particle inspection was reached. This can be explained by the sketches in Fig. 4. (All parts used for this experiment were fabricated of high-carbon toolsteel and were hardened and drawn to Rockwell C-62 to 64.)

Figure 4 at left shows a normal "magnaflux" paste buildup formed on an unplated specimen, locating a grinding crack on the order of 0.007 in. deep and 0.0005 in. wide at the mouth.

After having been correctly magnetized, any discontinuity occurring at the surface forms a flux leakage area directly over the fracture. The magnetic lines of force are indicated by the light parallel lines and continue to run in a horizontal direction until they reach the discontinuity. At this point, they will arch above the surface; this escape area is a strong, tiny magnet which readily attracts the fine particles. The buildup will always exceed the width of the fracture, and in the sketch is approximately 0.0025 in. high. In other words, the discontinuity is greatly magnified and the magnetic particles fill the flux leakage area on the surface.

The central sketch in Fig. 4 explains what happens to the flux leakage field and particle buildup when the same part has been plated with 0.004 in. of hard chromium. (In viewing the central and right-hand sketch hold in mind the one important fact that hard-chromium plate is a nonmagnetic substance.) The discontinuity is now below the surface of the part, as the surface has been elevated 0.004 in. by the annexation of hard, nonmagnetic chromium. Consequently, the extremity of the flux leakage field is approximately 0.0015 in. below the actual surface and has no appreciable attraction to the powdered inspection medium.

When thinning the chromium surface either by grinding or a thin plate, a portion of the flux leakage area will extend above the surface, as shown in the right-hand sketch of Fig. 4. The chromium surface in this case has been ground and remains only 0.0015 in. thick. The flux leakage area still exists but only the portion above the plating attracts the oxide. A small buildup occurs, often too minute to be detected or properly evaluated with the naked eye. These statements are substantiated by the micros in Fig. 5.

Photomicrograph at left of Fig. 5 shows a normal magnaflux buildup over a grinding frac-

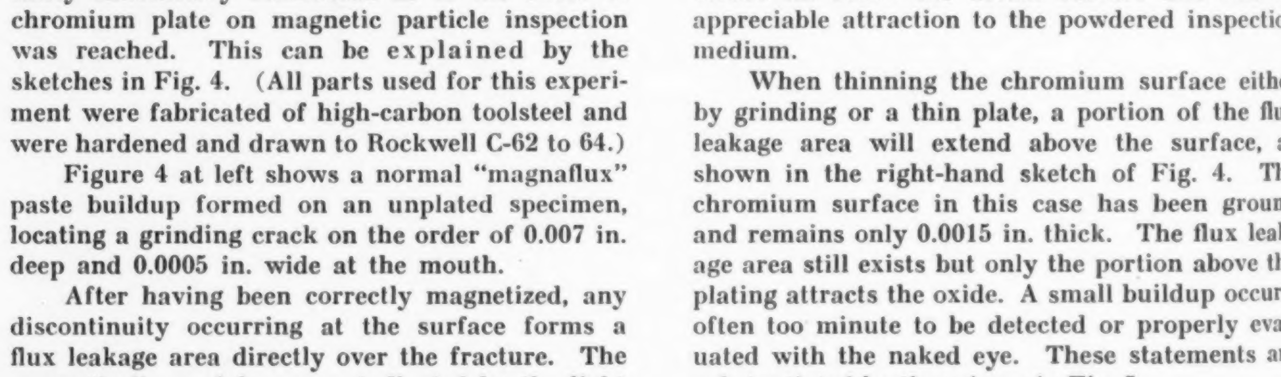


Fig. 4 — Sketch Showing How Thick Chromium Plate Obscures Magnetic Indication of Grinding Crack 0.007 In. Deep and 0.0005 In. Wide at Mouth

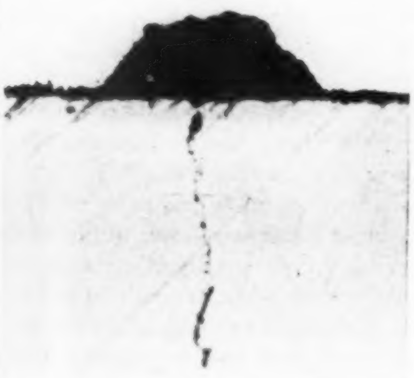
ture comparable to the crack in Fig. 4. The buildup measured microscopically is 0.0027 in. While the appearance of the fracture does not show the mouth opening to be of great width, it must be understood that a discontinuity of this nature does not run uniformly through the specimen and will fluctuate in appearance pictorially. (This fracture was very nonuniform in both mouth width and depth; further grinding and polishing of the micro would show a great variation in its appearance.) Therefore, the reader should not be misled by comparing the discontinuity and the size of the particle buildup. However, the specimen is made up of an ideal material in order to take advantage of the maximum amount of magnetic retentivity. The defect, which is transverse, produces the greatest possible disturbance or flux leakage field, since the part is longitudinally magnetized.

The central photomicrograph in Fig. 5 pictures a like fracture plated with 0.004 in. of hard chromium when magnetized. Treated in the same manner as the left-hand view it fails to produce an indication on the surface. The chromium surface is, of course, a nonmagnetic material which has bridged the discontinuity and has elevated the inspection plane above the flux leakage area. The defect now becomes subsurface and has lines of force existing in the magnetic material only (with the exception of those that leak across the gap and are caused to pass through the chromium). This path of magnetic flux, that *does* bridge, is not strong enough to cause a leakage area on the surface, but falls short approximately 0.0015 in. (Again we remind the reader that these specimens were tested using residual magnetism.)

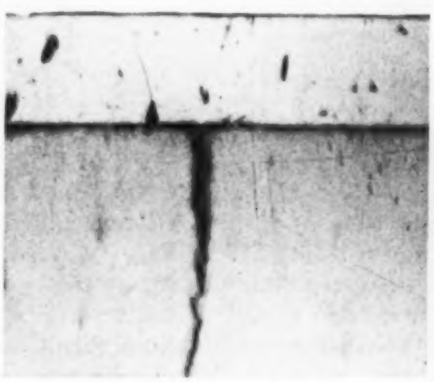
In order to afford a better understanding of the right-hand micrograph in Fig. 5, refer to the corresponding diagram in Fig. 4, which illustrates a chromium surface ground down to 0.0015 in. Also note that only a small portion of the flux leakage field exists above the chromium; therefore, the buildup or indication is likewise limited. After several attempts, we were fairly successful in preparing this photomicrograph. The greatest problem was to hold the particle buildup directly over the fracture while polishing the specimen. Results were finally attained by sectioning the specimen, magnetizing and applying the magnaflux bath. Using forceps, we immersed the specimen in a beaker of carbon tetrachloride in order to remove the excess oxide and dry up the suspensoid. The piece was then dipped in thin, clear lacquer solidly fixing the indication to the surface. After drying, it was mounted in lucite and the face polished. As lucite mounting necessitates the use of heat and pressure, it did slightly compress the height of the buildup and a small portion of the left corner broke off.

In summarizing the preceding theory, chromium plate has a tendency to hide the defects, placing them in a subsurface category. A subsurface defect in a magnetic material, such as toolsteel, will have lines of force existing throughout the entire substance. This type of defect will greatly affect the flux leakage field above the surface over the defect. However, when the surface of steel, a magnetic material, is plated with a thick plating of chromium, a nonmagnetic material, the magnetic lines of force are concentrated in the steel, and even though the flux leakage area extends above the surface of the steel, it is not strong enough to attract and hold the ferromagnetic particles on the surface of the chromium above the fracture. For this reason, it is necessary to use the continuous method of testing rather than to rely on residual magnetism, since the former provides greater flux density.

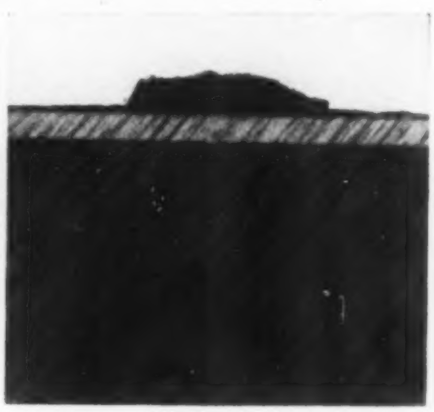
Fig. 5 — Micrographs at 150 × Normal to Defective Surface, Confirming Sketches of Fig. 4



Normal buildup over grinding crack in hardened tool, not plated



No buildup when crack is covered with 0.004 in. of chromium



Small buildup when crack is covered with 0.0015 in. of chromium

Fig. 6 — Plug Gage With Circumferential Crack Was Half Plated; Inspection Shows Crack Only on Bare Steel. 2 ×

As proof of the above, Fig. 6, taken double size, is included. This shows a tool which had been magnetically inspected before plating and found to have a complete circular crack. It was then plated with approximately 0.008 in., followed by selective stripping of the chromium plate from one-half of the longitudinal section with stop-off lacquer. The chromium was then removed electrolytically by making the tool the anode in a caustic solution. It was obvious that the indication stops where the chromium begins.

If we were to encounter subsurface defects, such as metallic and nonmetallic inclusions, in similar parts, they would be placed to even greater depths by plating and would, in all probability, be impossible to locate during magnetic inspection by the residual method.

As this was a constant source of trouble, representative samples were magnafluxed as follows:

1. They were inspected by our standard method, a.c. residual. Results — negative.
2. They were tested with d.c. residual. Results — showed slight patterns which could not be correctly evaluated.
3. Inspected by full wave rectified a.c., continuous method. Results — several parts showed large areas of small and fairly defined grinding indications, while others failed to give any evidence of defects.
4. The parts not appearing defective, however, were fractured into several pieces when dropped from eye level to the concrete floor, and showed metal discoloration on the fractures.
5. A full wave rectified a.c. unit was then equipped with a coil delivering approximately 25,000 ampere-turns. This coil ran continuously while applying the inspection bath and during the visual inspection. Results — very good; particle buildups appeared, well defined and uniform, but would flow off due to their own weight when the current was interrupted.

Conclusion — By careful consideration of the results of these five methods, it was evident that the rectified a.c. continuous method is superior for the location of subsurface defects or defects lying below a hard-chromium surface. Also that while the residual method magnaflux units are not capable of producing completely satisfactory results under these conditions, the continuous method equipment can handle, with good results, a variable of this nature.

It is our opinion that, due to its greater inherent penetration, the continuous method gives better results on chromium-plated parts. When using the residual method, one must rely entirely upon the amount of magnetism which will remain in the part after the magnetizing force has been discontinued. Also, the type of current used makes little or no difference in the final outcome when tested residually.

The continuous method takes advantage of a minimum amount of magnetism, intensifying the induced magnetic field. Therefore, the flux leakage areas produced by these tiny defects are at their peak of attractive powers while the current is flowing through the part. (This condition, of course, may vary somewhat in different steel compositions.)

Experimental Tools — As was previously mentioned, we did follow through with experimental tools to determine the cause of the fractures and our ability to detect known defects by magnetic particle inspection. The experimental tools were used with the profile die for final formation of the caliber .50 bullet. (It is extremely important that the contour of this component be uniform in every respect.)

The fabrication job involved the following work sequence: *(a)* Grind the outside diameter of the tool. *(b)* Plate the surface with approximately 0.004 in. of chromium. *(c)* Finish grind the plated surface. The general procedure followed with the first group of six tools was to draw one-half the lot of punches at 350° F. for one hour after each operation to determine if such stress relief would eliminate fractures. Although final results showed less fractures on the group which had been drawn, we were not convinced that heat treatment was the entire answer. The photograph on the next page, Fig. 7, shows six of these punches. The lower three tools were drawn at 350° F. for one hour.

A further study was made on nine punches. In general, the same procedure was followed as with the six photographed in Fig. 7, except that before rework, three tools were drawn to Rockwell C-58, and a special check was made of the indications resulting from plating and stripping without grinding.

Three of these tools were plated and stripped without grinding; magnetic particle inspection

showed no indications. It should be kept in mind, however, that some of the tools were discolored on the fracture of the base metal after breaking. Since they showed no indications previous to plating, it is possible they were highly stressed and then fractured during the plating operation, due to hydrogen embrittlement. This would account for the discoloration on the fracture. The three tools which were drawn to a lower Rockwell hardness still showed a few small fractures after grinding, plating, grinding and stripping, but they were not so extensive as in those tools not drawn.

Therefore, it was concluded that neither hydrogen embrittlement from plating nor the high Rockwell hardness was the chief cause of the fractures. However, changing the feed and dress of the wheel used for grinding the plated surface did produce fractures. It is our belief that when grinding hard chromium plate the individual grains in the grinding wheel lose their cutting edge more rapidly than when grinding steel. If the individual grains are held too tightly by the bond and are not allowed to break loose when they become dull, they will cause overheating which, in turn, causes grinding cracks or builds up dangerous stresses.

After the first work, above described, we experimented further with a long draw or temper. This fabrication consisted of caliber .30 bullet jacket draw punches. They were turned, hardened, ground, chromium plated, and finish-ground within 0.0005 in. tolerance. Approximately 0.002 in. of chromium was applied. Prior to our experiments with a long draw the percentage of rejects ran from 20 to 70! The best results were obtained by a 16-hr. draw at 350° F. Rejections on approximately 3500 of these tools did not exceed 0.5%! The tools were fabricated from the best grade of carbon toolsteel and normally will be Rockwell C-62 to 65 hard. This long draw resulted in dropping the hardness to C-58 to 60.

We believe that all parts should be properly stress relieved or drawn prior to and following the plating process. It is also advisable to make sure that an accurate job of inspection is being performed on each individual part.

It is only natural that users of tools and dies desire high Rockwell hardness. However, when a tool or die is to be plated it is unnecessary to maintain this hardness. The part should be hard enough to hold up under the load applied to the chromium surface, without enough deformation to cause cracking or spalling of the chromium. Nevertheless, it can be drawn enough to remove dangerous stresses without reducing the hardness (and strength) too much.

By way of summary, we believe that *(a)* it is possible to use magnetic particle inspection in testing hard chromium-plated parts, *(b)* magnaflux equipment *designed to do the job* will produce the best results, and *(c)* care should be exercised in such operations as drawing and grinding during the fabrication of chromium-plated tools.

Since our experiments and analysis of this problem the foregoing recommendations were put into force; thereafter we encountered very little trouble even though there was a large increase in the use of chromium-plated tools.

A great deal of the success in the foregoing tests was due to the uniform control and plating techniques of our colleague, Gerald B. Higdon. We also wish to thank the Magnaflux Corp. for splendid cooperation and use of equipment in the Chicago laboratory.

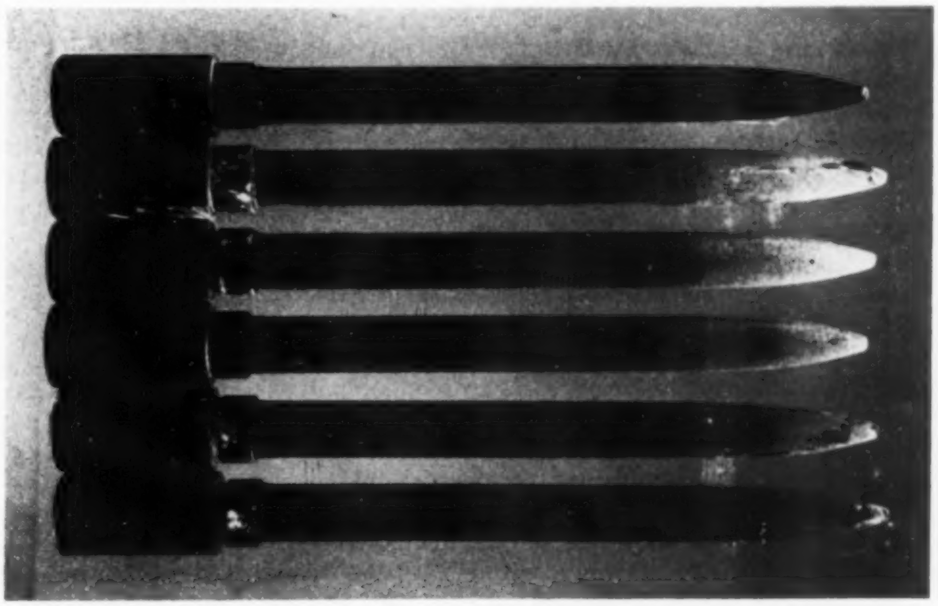


Fig. 7 — "Magnaglo" Indications on Caliber .50 Bullet Pointing Punches (About Half Size). Reading from top down: Ground; ground and plated; plating finish ground. Lower three have same sequence, although each was tempered at 350° F. for 1 hr. after each operation

CRITICAL POINTS

By THE EDITOR

ATTENDED a large meeting of the American Welding Society's Cleveland Section at Lincoln Electric Co.'s plant, and approved JIM LINCOLN's hopeful words about the future of welding, knowing from personal experience how far it has traveled in the last 25 years. The metallurgist and welder, in the last generation, have learned a great deal about the welded joint itself, enough so there is truth in the saying that "anything can be welded". There is actually some danger in this, for welding has often been and will often be used for commercial fabrications without knowing whether the particular metal is "weldable" or the particular welding process is suitable. LINCOLN emphasized that the future of welding is in the designing engineer's hands; methinks considerable caution is in order, for although we know a lot about the welded joint, we know comparatively little about complicated and large welded structures. It's the structure as a whole, not the joint as a part, that is likely to run into trouble. Witness the wartime record of all-welded ships, 5000 of them, built during the war. Rear Admiral JOHNSON, chairman of the board of inquiry, reports that about 1000 of them sustained fractures of which 127 were classified as serious, and eight vessels were lost. "Every fracture examined," he said, "started in a geometric discontinuity or notch, large or small, resulting from unsuitable design or poor workmanship . . . . and proceeded in steel which was notch sensitive" at the temperature obtaining. . . . . Prior to the plant inspection, HAL KNEEN, vice-president in charge of manufacturing of Lincoln Electric, said something that I like: "It's the equipment you *don't* see in the plant, the operations we *don't* do, that we are proudest of!" He described a continuous drive for simplification; once the decision is made to make a frame of welded steel, then all efforts are bent to do as little welding as possible and do it as quickly as possible; once the decision is to stamp a part to shape, then the effort is to build dies accurately enough and put power enough behind them so *no* machining will be necessary. . . . . Worthy of note also is the generous use of hard facing alloys, welded on the critical areas of dies, both in original construction and for repair. From a metallurgist's viewpoint, there should be a large future field for the manufacture of composite materials, using automatic welding processes for building up a homogeneous layer — thin or thick as desired — of alloys having special properties on appropriate areas of machine parts made of common metals.

How strong should a joint be?

TO A Cleveland Chapter meeting and heard President BOEGEHOLD discuss the new H steels (H for hardenability bands). He showed how information, recently acquired about cooling rates on Jominy test bars, enables one to predict accurately the hardness-depth curves of round bars or wide plates, and argued for an even narrower hardenability band on important steels so specified — primarily a matter of a narrower carbon spread in the chemical specification. His point was that in certain instances (such as shell hardened axle shafts, rear axle gears, torsion springs, and bearing races) the hardening gradient was intimately connected with the internal stresses in the finished part, and would make all the difference between a hardened part with surface in desirable compression, and one infested with hardening cracks. . . . . Steel producers in the audience pointed out that the problem was largely one of economics. Narrow hardenability limits are of most value to the mass production industries, where precision heat treating is expected from continuous quench-and-draw furnaces. In these it is desirable that draw temperatures remain steady — any change, heat to heat, means furnace delays and a rise in the number of rejected parts that are off-limits for hardness. The present H steels can be delivered by steel mills without price extras because the expected number of heats to be diverted for off-hardness are balanced by an equal number of

Can hardenability bands be narrower?

heats with acceptable hardenability that would otherwise be rejected for off-chemistry. On the other hand, narrowing the hardenability bands would immediately increase the number of diverted heats; the matter might be pushed to the limit where the automotive industry would slow down because the steel mills could not select enough heats to enable their customers' drawing furnaces to run without slowdowns for occasional adjustment!

THIS MATTER inevitably led to some comparisons between electric and openhearth steels and the problem of rapid chemical analysis of a bath about to be tapped. HARRY McQUAID reminded his hearers that the variation within a single ingot, due to the natural forces of segregation, prevented anyone from making truly uniform steel. There is also a drift in composition from first to last ingot in the cast, due to inevitable reactions in the ladle — an approach to equilibrium. (Something might be done about this with graduated additions to the ingots.) But the prime cause of diverted heats of basic openhearth steel (and this furnace makes three-quarters of the tonnage of alloy steels used in the heat treated condition) is the oxidizing conditions in the bath. Suppose the final analysis reaches the first helper as soon as 10 min. after he takes the sample; from 10 to 12 min. is needed for the final additions to be properly melted, and in all that time the important elements (carbon, manganese, and chromium) are slowly moving out of the metal. When these variables are added to variables in the composition and errors in the weights of the additions, it is strange that so few heats actually have to be diverted. . In the electric furnaces, on the other hand, conditions are much more stable; the bath can be held long enough for chemical analyses and for melting the necessary additions; chemical variables are then limited to changes *after* the steel leaves the furnace. . . . . In view of the inherent limitations of the openhearth process, EARLE SMITH, Republic's chief metallurgist, said that he would probably first use self-reading spectroscopes, when they are rugged enough for the melting shop, on carbon rather than alloy steel, to catch the minor tramp elements that have such an important effect on the surface quality of steels used for coated products, particularly tin plate for making food cans.

The problem of hitting the analysis on the nose

REMEMBERED one penalty of news-worthiness: Anyone interesting enough to the daily newspapers to be quoted — or rather misquoted — must learn to bear it with humor. Thus, on the event of the Campbell Memorial Lecture at the last ⊛ convention, Dr. AUSTIN was accused by the New York *Herald-Tribune* of calling our old friend cementite a "Strange Compound in Steel. . . . . It consists of three atoms of iron joined to one atom of carbon, the iron thus acting differently than in all other known compounds." The New York *Times* was equally alert: It reported remarks by ARTHUR UNGER of Pullman Car Mfg. Co., who told the American Welding Society that his outfit had "the world's largest persistence welding fixtures". Dare this be ascribed to a slip that passed in the type? . . . . Possibly also the eager publicity agent for Stevens Institute of Technology was also trained in the reportorial profession, for he says, in announcing a research contract with the Navy: "Its purpose is to gain further understanding of the crystallization which occurs when metal parts are in vibration, as for instance in a crankshaft. Radioactive tracers will be used to follow the motion of the atoms in the metal."

Slips that pass in the type

Eve and the Isotope

By Marcia Lee Anderson
Hollins College, Va.

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EVE and the isotope
Have much in common:
Both, in the cosmic dance,
Are variants.
Behold in Eden
Adam without woman
Noble atomic weight and scope achieves.
Behold again:
Lo! in a crazy trope,
Eve.
Eve and the isotope
Have much in common.
But who can analyze
One fairest daughter?
Who can anatomize
This heavy water?
Adam, Adam,
Abandon hope:
You can only fathom
An isotope.
The bed-companions of
Uranium
You may at last be able
To chain and label;
But woman's love,
Like woman's cranium,
Is volatile, insoluble, unstable.
Not Solomon could at his pleasure wive
235,
Or fondly isolate
238.

FRACTOGRAPHIC STRUCTURES IN ZINC

By CARL A. ZAPFFE
Metallurgist, Baltimore, Md.

Photography by George A. Moore
Battelle Memorial Institute

A PRECEDING ARTICLE in *Metal Progress* (August 1946, page 283) presented several fractographs showing the unusual patterns and structures found on the nascent cleavage facets of bismuth, several of which remain to be explained. Those pictures, as well as the ones presented in this article, were taken directly on 8x10-in. plates, and the fields are in focus across the whole plate. Since a natural cleavage is being viewed, at from 250 to 500 diameters, this not only represents an accomplishment in photography, but also indicates that useful areas of these fractures are substantially flat.

Since zinc is easily studied fractographically because of its tendency toward brittle cleavage, fractographs of zinc might provide informative comparison with those of bismuth. (Crystallographically they are in different systems, zinc being close-packed hexagonal like magnesium and β chromium, whereas bismuth is rhombohedral like its two near chemical neighbors, arsenic and antimony.)

Cast zinc of high purity was therefore treated in the same manner as the bismuth, specimens being machined and broken as standard V-notch impact specimens. The fractured ends were mounted in Wood's metal and studied by means of the technique described in the earlier paper in V. 34 of *Transactions* (1945), page 71.

Probably just as for bismuth, the structures observed in the three fractographs presented in Fig. 1 to 3 can be classified basically as *(a)* twin bands, *(b)* secondary cleavages, *(c)* fissures, and *(d)* striae. Ample differences exist, however, to distinguish fractographs of bismuth from those of zinc, as one may see by comparing the figures on these pages with those in the preceding paper in *Metal Progress.*

Twin Bands — As with bismuth, twin bands are everywhere prominent in the deformed zinc. However, the bands in the zinc have a somewhat different appearance, culminating in the remarkable registrations of Fig. 1. There the deep profiles might remind one of gougings from mechanical mistreatment during polishing; but the markings lie crystallographically at exactly 60° to one another — and it will be remembered that the facet is nascent and untouched.

Secondary Cleavages — While secondary cleavage is undoubtedly expressed in the fractographs of zinc by some of the markings there, the riffled structure seen in bismuth was not observed in the zinc. The large X in Fig. 2 may represent secondary cleavage, rather than twinning. Zinc, whose close-packed hexagonal structure is not too unlike the rhombohedral structure of bismuth, similarly cleaves on the (0001) basal plane.

Fissures — Networks of fissures are at least as prominent in the zinc as in the bismuth. Once again, close examination often reveals their progress along exact crystallographic directions which maintain the expected 60° symmetry.

The fissures in Fig. 2 are especially interesting because of their likeness to maps of extensive drainage systems, yet they plainly comprise four separate families or networks segregated by the arms of the large X. The faint horizontal twin bands overlying the whole field prove that all these structures lie within *one* grain; consequently these groups are intragranular, and it is probable that they express some nonuniformity in the growth of that grain.

Figure 3 at 500 × also shows these fissures prominently, two at upper right apparently having opened to provide virtually complete separations. Viewed at right angles, such separations would appear as a rough surface comprising tiny, juxtaposed facets, in contrast to the flat, expansive and

reflective surfaces of the planar cleavage which afforded the field of the photograph.

Some of the other fissure markings in the fractographs are so extensively straight that they plainly reveal their crystallographic nature. Failure along the fissure running vertically from the upper left, for instance, would result in a facet especially suited to fractographic examination from another angle, similar to the one providing the present field; its present registration is therefore the profile of that facet.

Striae — These interesting surface markings, so pronounced in bismuth and rocksalt, are less prominent in the fractographs presented here for zinc. They may be observed, however, at the bottom of Fig. 3 (and in all of the original photographs) as exceedingly fine and exactly disposed lines resembling fine polishing marks lying at 60° to one another.

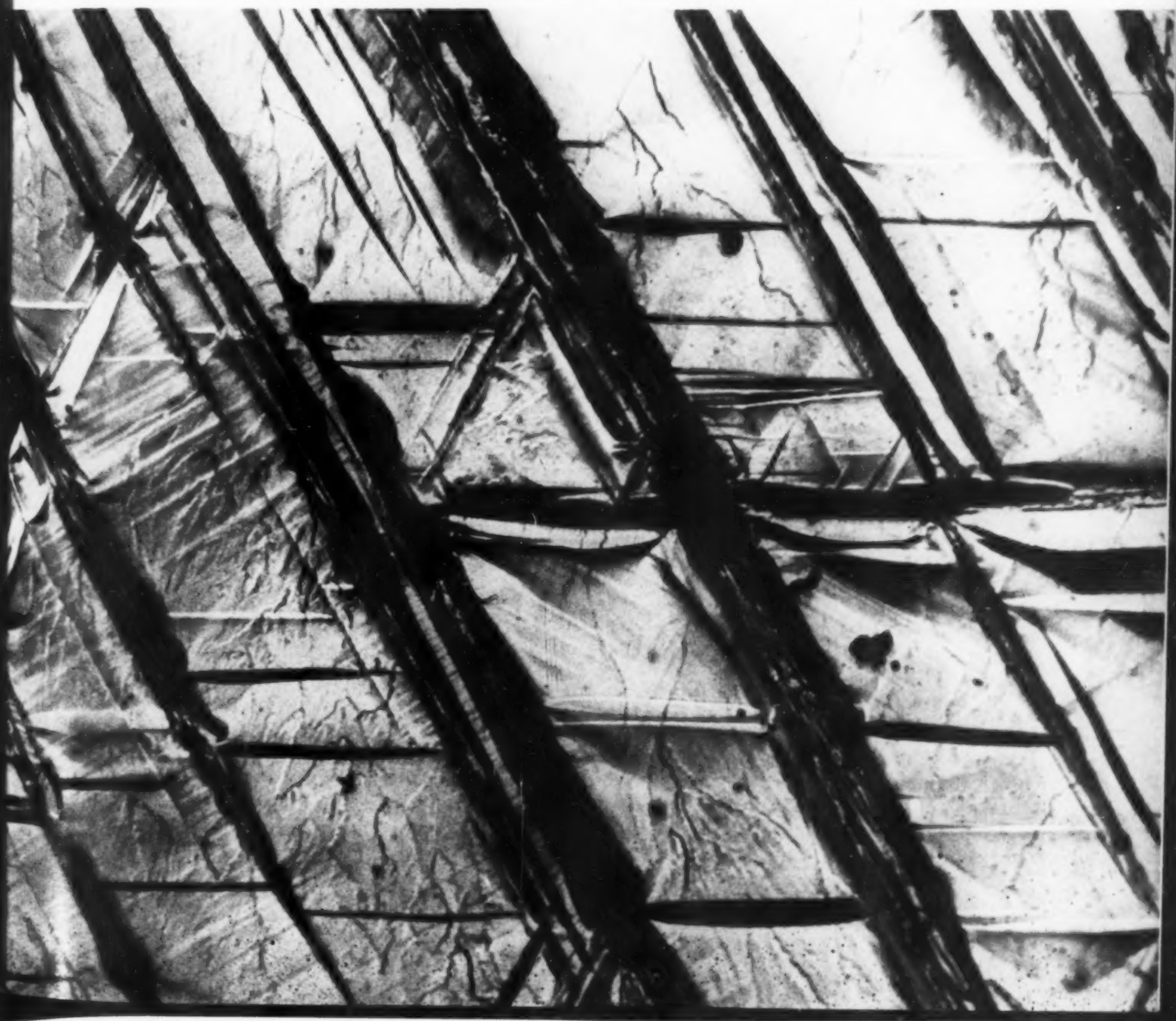
Conclusion

These structures have been discussed in their supposed order of formation, which is the same as described for bismuth in the preceding article. Figure 2 further verifies this order by showing the horizontal twin bands, for example, proceeding across fissures with uninterrupted geometry, but showing marked displacement across the shear surfaces forming the X, which appear to be secondary cleavages. (The assumption is again made that a twin would not form with perfect geometry throughout a grain already containing a network of separations.)

Consequently, like bismuth, zinc may be assumed to fracture according to the following progression of phenomena:

1. Twin bands, forming during the preliminary period of plastic deformation.

Fig. 1 — Twin Bands in Fractured Facet of Cast Zinc, Registering at 60°. 250 ×



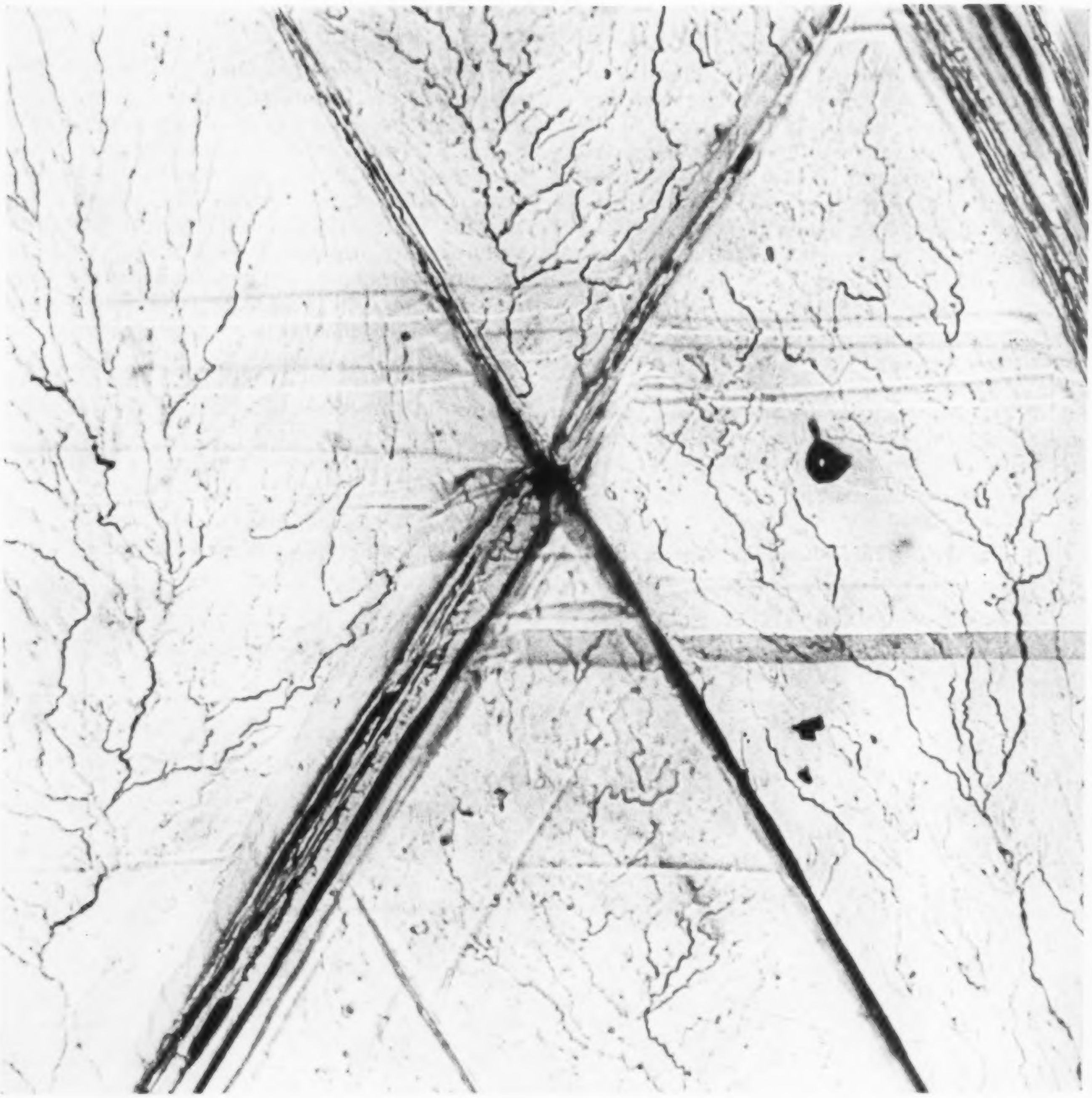


Fig. 2 — An X Marking in a Single Grain That May Be Secondary Cleavage Rather Than Twinning, 500 ×. Note four separate families or networks of fissures

2. Partial separations, developing along both primary and secondary cleavage planes.

3. Complete separation, occurring along a primary cleavage plane.

4. Possible crystallographic reorganization of a thin layer of the newly formed surface.

Stage 2 provides the widest assortment of patterns, apparently because inherent weaknesses in the crystal there reveal themselves. Since these patterns register upon the primary cleavage facet of Stage 3, they cannot concern the weakness of a primary cleavage and must therefore be direct evidence of an imperfection structure, a relatively unexplored phase of metallurgy obviously of great importance.

Stage 4 refers to the so-called striae first observed in bismuth. Their nature is not understood; but their relationship to the other patterns suggests that they may represent a final crystallographic reorganization of a microscopically thin surface layer at the instant cleavage develops that new surface.

Fig. 3 — Fissures in a Single Grain, More Definitely Marked. Despite the meandering course of some of them, the extensive traces of some along geometric planes indicate that they follow small steps each in a crystallographic direction

BIOGRAPHICAL NOTES OF EMINENT LIVING METALLURGISTS

Francis Edwin Bash

MANAGER, TECHNICAL DEPT., DRIVER-HARRIS CO.

FRANCIS EDWIN BASH

TRADITION certainly indicates that the manager of the technical department of Driver-Harris Co., in Harrison, N. J., undoubtedly missed his calling when he got into metallurgy. That fate had clearly intended that he should be a Congressman, or even President, is implicit in the circumstances of his background, for he spent most of the first ten years of his life in a log cabin. Not only that, but he had to walk three miles through the woods to school — which was *also* housed in a log cabin. These homely facts, properly exploited at election time, would have been enough to have kept him cozily ensconced in a sinecure for life.

But despite the fact that metallurgy is obviously not his manifest destiny, FRANCIS EDWIN BASH has not turned out too badly. Today, after about 30 years of wrestling with the problems of pyrometers, thermocouples, heater elements, and high temperatures, he is one of the top men in this field; he has been responsible for the establishment of many of the tests and standards now generally used in his branch of the metallurgical industry, and is an outstanding specialist in high-nickel alloys. He formulated the "life test" for electrical heater wire which, with some refinements, is now the standard for the entire industry making appliances and heaters. It was at his request that the American Society for Testing Materials organized its Committee B-4 with the duty of standardizing testing and development procedures for electrical-heating, resistance and related alloys. He has been secretary of that committee ever since its first meeting in 1925, and apparently holds life tenure. In this country the standard life test is one of the A.S.T.M. standards, but in Europe it is usually referred to as the BASH-HARSCH test, a fact which understandably pleases him. (BASH and J. W. HARSCH of Leeds & Northrup Co., who is chairman of the same committee, authored the definitive papers on the subject.) As a result of this accurate yardstick, the life of high-temperature heating alloys has increased 20 to 30-fold.

Not content to stick exclusively to resistance wire, BASH has done added work in the high-temperature alloy field as a long-standing member of the A.I.M.E.-A.S.T.M. joint high-temperature committee on the effect of temperatures on metals. His general interest in ordinary metals for ordinary as well as theoretical purposes is also kept up through active membership in the Metal Science Club of New York.

BASH also puts in a hard day at the office where he and his staff keep a sharp eye on the quality of the 86 different alloys Driver-Harris produces and sells, carry on development work on plant processes for the company and its customers, and develop new alloys. Alloys in production — chiefly nickel-base — are used for the most part by manufacturers of industrial furnaces, electrical appliances, electrical measuring instruments and radios. Bash is well suited in personality, as well as in professional attainments, to the business of getting around and keeping up with the many and ever-different problems of this complex industry. He is gregarious, relaxed and friendly; he would not work well in an ivory tower.

Resourcefulness and energy are perhaps a natural consequence of a correct choice of a family to be born into. The forebears of FRANCIS BASH were rugged people who really went West during the 19th century and made themselves at home in the wilderness. His grandfather, who came originally from Indiana — it was not far enough west, even then — was port commissioner of Port Townsend, Wash., in a day when it was the principal port of entry in those parts. His father was a mining engineer who led the peripatetic life of his calling, moving from place to place, most of them in remote valleys where gold is sometimes found. He was also once a cattle rancher and, at one time, a guide for General SHERMAN.

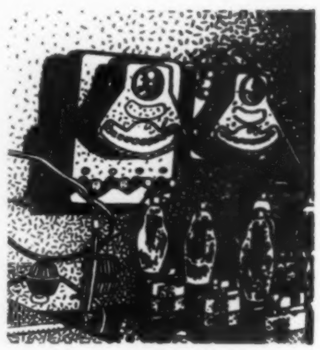
The subject of this appreciation was born in Port Townsend in 1893. When he was three, his father moved the family to the wilds of British Columbia where he was to be superintendent of a gold mine, and it was here, in the log cabin aforementioned, that FRANCIS spent the next seven years of his life. It was perched on the edge of a 500-ft. cliff. Supplies were brought in on pack horses; an occasional stagecoach brought mail. During the winter, when the cabin was snowbound and he couldn't get to school, his mother taught FRANCIS his three R's. In later years, whenever his own children complained about the minor irritations of their existence, he could not help but harken back to the rigors of his childhood in the depths of the Rocky Mountains.

When FRANCIS was ten, his family moved to Seattle, where he entered 5th grade — later high

school at Lake Chelan and in due course entered the University of Washington to study chemical engineering. He transferred to Wisconsin in his junior year and received his B.Sc. there in 1916. Three years later he returned and got his Ch.E.

FRANCIS BASH worked his way through college in the homespun manner. The money he earned during the summers as a pick-and-shovel laborer, harvest hand, or carpenter, he eked out at school by selling shoes and doing odd jobs.

In 1916, BASH started out his metallurgical career in the research department of Leeds & Northrup Co. in Philadelphia. His first chore was to help on the development and design of an optical pyrometer of the disappearing-filament type. The war in Europe had, by this time, cut off the supply of many of the chemical and metallurgical products which were normally imported from Germany, and Leeds & Northrup, like many another firm, was forced to re-create these materials for themselves or do without. BASH's next job was to reproduce the German alloys known as Constantan, needed for the manufacture of thermocouples, and Manganin, used in various electrical instruments.



He was transferred from research to production in 1919, and for the next year and a half he was busy building electric furnaces for heat treatment. "This work," says BASH today, "was a lot of fun" — a fairly typical remark by a man who gets intense satisfaction out of whatever he is doing. In 1920, L. & N. increased the fun he was having in the furnace department by adding general factory production control to his duties.

In 1923, BASH left Leeds & Northrup to join the Electrical Alloy Co. in Morristown, N. J., where he took charge of the technical department, the duties of which included alloy and process development, customer service, and general engineering. One of his first tasks was to develop a rapid and discriminating life test for electrical heater wires, and it was at this time that, as mentioned before, he induced the A.S.T.M. to set up Committee B-4. Electrical Alloy Co. was acquired by Driver-Harris Co. in 1925, and three years later FRANCIS BASH moved over to the home office in Harrison, N. J., to become head of the general technical department.

Through the years, BASH has found time to prepare quite a fistful of technical papers for the A.I.M.E., A.S.T.M., and A.S.M., and anyone who contemplates writing a definitive "LIFE OF BASH" (or anyone who is interested in temperature measurement or the metallurgy of heating alloys) had better sit right down and read them. The entire list of these papers can be found in "Who's Who in Engineering".

It is always interesting to know what busy men do when they are not busy. The late J. P. MORGAN, for example, used to go cruising on his yacht Corsair with a large box of mystery books. BERNARD BARUCH, of course, sits on park benches. Other men like to fish, and BASH is one of these. HARRY D. MCKINNEY, who is works manager of Driver-Harris and a former treasurer of , and who occasionally goes with him up into Canada, asserts that BASH is not a fussy angler; says that he will fish any place for anything, with any bait. This, it can now be revealed, is not strictly true. Actually, BASH has a low opinion of eastern fishing; he says that the equipment, time, and protocol required to induce one small, meek trout to leave the water and enter the frying-pan is entirely disproportionate. This heresy is understandable, however, when we consider his early environment. Out in British Columbia at the turn of the century, when dinner time approached, young FRANCIS would commonly stroll from his cabin down to the bottom of the canyon, throw in a bent safety pin, and land a 10-lb. trout.

BASH plays golf in the low nineties, and demonstrates a steel-trap mind at bridge. He is joined in these diversions by his wife. Raising five children has kept him pretty much on the jump, and the more recent arrival of seven grandchildren has not lessened his pace. For reasons that need not be gone into here, BASH feels strongly that middle-western colleges provide the best atmosphere for the growing child, and all of his — three boys and two girls — have therefore dutifully attended Michigan State. Apparently, this has done them no harm.

His wife, who was BARBARA SMITH when he met her in Seattle some years ago, shares her husband's love of the outdoors, and when the children were small the entire family used to camp out in the woods all summer long. As a result, BASH claims that the children never had colds in the winter. This is an interesting hypothesis and one that might well be incorporated in a learned paper. Besides, it would add a little variety to the usual output of the B-4 Committee which, after a quarter of a century, must be getting fed up with heater-wire life tests.

EDWARD C. MCDOWELL, JR.

DIFFICULT METALLOGRAPHIC MOUNTS

MOUNTING FOR EDGE EXAMINATION

By ANDRE HONE
Head, Physical Metallurgy Division,
Aluminium Laboratories, Ltd.,
Kingston, Ontario, Canada

MANY of the problems encountered in a metallographic laboratory require a microscopic examination to be made at the very edges of the specimen. If the specimens are not properly prepared, the edges may be rounded-off during polishing, thus preventing such observation.

Rounding-off, for the most part, is caused from lack of proper backing-up at the edge. This may be alleviated in sheet samples by pack mounting — that is, by bolting several sheets tightly together after interleafing them with annealed foil. Samples having an irregular shape or with quite a rough surface are usually mounted in a substance with a low melting point, or preferably in a plastic such as bakelite (phenol formaldehyde) or lucite (methyl methacrylate). Since there is a lack of intimate contact between such mounting materials and the specimen mounted, there is usually enough of a discontinuity between mount and sample to cause some rounding-off or staining of the edges of the sample.

A method which consists of coating the sample, prior to mounting in the conventional way, with a substance having sufficient penetrating power, adherence, hardness and elasticity* has been developed in our laboratories by E. C. Pearson and has been found to give satisfactory results for aluminum and its alloys. Prior to coating, the specimen should be thoroughly cleaned in a suitable solvent such as acetone. Depending on the type of sample, the acetone may be applied by rubbing with a clean cloth or the specimen may be immersed and the excess acetone blown off with compressed air.

The specimen should then be dipped in a solution of two parts of the adhesive (Bostik No. 7008) and one part methyl hydrate, after which it should be dried in a gentle breeze of air from compressed air line or fan. Drying should be continued until the coating is no longer sticky, which usually requires approximately 10 min.

Following this, three additional coats of Bostik should be applied and dried in the same

*The substance used is "Bostik No. 7008" and is obtainable from the B. B. Chemical Co., 784 Memorial Drive, Cambridge, Mass., or 2160 Bennett Ave., Montreal, P.Q.

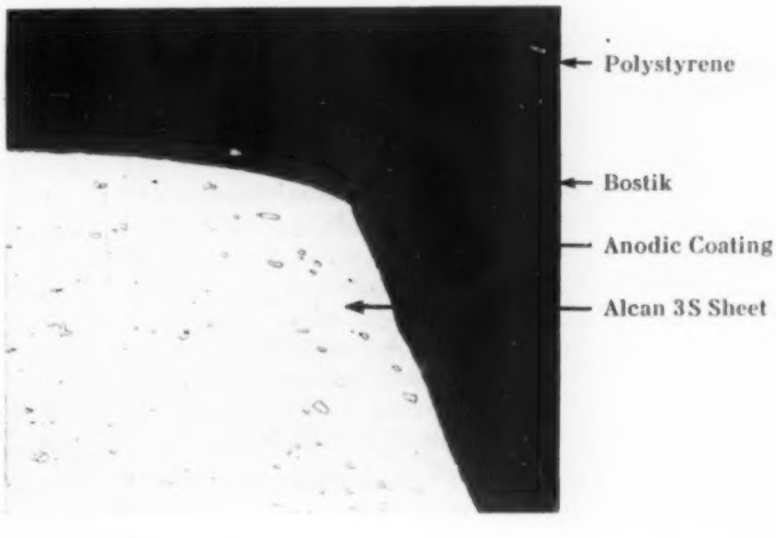


Fig. 1 — Corner of Anodized Alcan 3S Sheet; Not Etched; 500 ×

manner. The drying time may have to be increased somewhat on the third and fourth coats and will vary considerably, depending on the amount of solution left on the sample. In certain samples it is necessary to increase the fluidity of the adhesive in order to secure proper penetration; a 1 to 1 solution may be used.

After diluting the adhesive with the methyl hydrate, the solution usually contains numerous gas bubbles. In order to obtain a more uniform

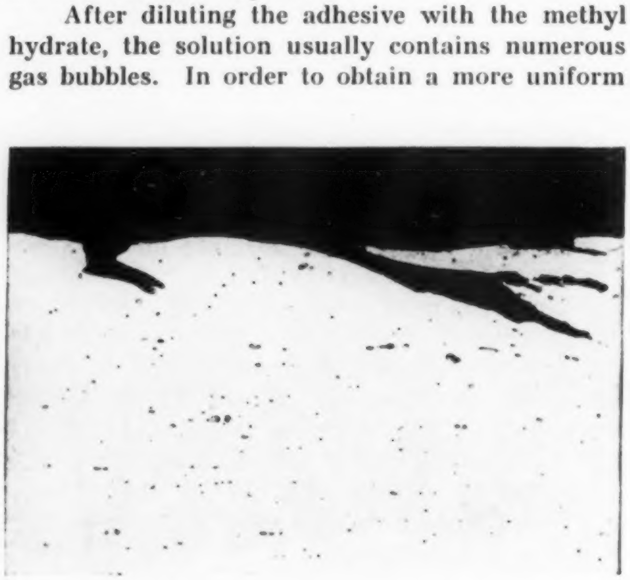


Fig. 2 — Surface Defects in Alcan 57 S Wire; Not Etched; 200 ×

coating it is well to clarify the solution by holding the container a few minutes in boiling water. (The mixture is combustible and should be kept away from a flame.)

After the specimen has been properly coated as outlined above it should be mounted in polystyrene,* using any of the usual type of hydraulic mounting presses. The mold, with metal insert and polystyrene powder, should be heated to 285° F. (140° C.) without applying any pressure. When this temperature is reached start pumping on the hydraulic jack in the mounting press, applying a load of 2500 lb. on a 1-in. diameter mold. The temperature should be held at 285 to 295° F. for 10 min., after which the load should be increased to 5000 lb.; and this temperature and pressure sustained for an additional 5 min. The mold should then be cooled to 140° F. (60° C.) and the sample ejected. A cooling jacket may be used, providing the pressure is maintained.

The polystyrene has a greater tendency to stick to the mold wall during mounting than other plastics, and difficulty may be encountered in removing the mount unless a thin coating of vaseline or other suitable lubricant is applied to the inside wall of the hollow cylinder. The sample may also tend to stick to the bottom plate unless the latter is lightly lubricated. Excessive vaseline, it should be noted, will cause a rough surface on the bottom of the sample.

Since these mounting materials are affected by the usual lubricating medium used on the metallographic emery papers for polishing aluminum and other metals — namely, kerosene and paraffin wax — "Virgo oil No. 38-P" (Shell Oil Co.) is recommended. Only a small amount should be put on the paper prior to polishing.

In some instances trouble may arise from relief polishing at the outer edge even if there is no gap between sample and mount. This tendency will depend to a large extent on the relative hard-

Fig. 3 — Edge of 0.062-In. Hole in Alcan 75S-T Rod; Not Etched; 200 ×

ness of the edge of the specimen and of the mounting medium immediately adjacent. In order to minimize this relief polishing it is necessary to obtain the maximum cutting action from the abrasive and cloth. Probably the most important factors influencing this are *(a)* the amount of water used, *(b)* pressure applied on the sample, and *(c)* speed of the wheel. The cloth should be just damp, as excessive water will increase the relief polishing. Lighter pressure and slower wheel speeds also will increase relief polishing. In order to eliminate the last fine scratches it is necessary to substitute a polishing action for the cutting action; such final polishing, however, should be kept to a minimum to prevent relief polishing.

Some of the applications where this mounting method may serve to advantage are illustrated in the accompanying photomicrographs. Figure 1 is an anodized sheet of aluminum alloy Alcan 3S. The photomicrograph taken at the corner illus-

*Dow Chemical Co.'s polystyrene (Styron R-1-K27 Fines) has been found satisfactory.

trates how the Bostik will flow into the gap in the coating, maintaining perfect contact and thus assuring proper backing-up during polishing. At this particular corner there seems to be some foreign substance at the bottom of the gap. In some instances specks of dirt may be lodged in these small cavities and may not be removed during cleaning. However, the adhesive flows around these inclusions and the result is probably just as effective as if they had been removed prior to mounting. This method of backing the sample also prevents the polishing away of the sometimes friable outer edge of certain thick anodic coatings.

Surface defects in a longitudinal section of Alcan 57S aluminum alloy wire are shown in Fig. 2. Here again the irregular surface may be properly backed-up with this method.

Another instance where this scheme might be used is illustrated in Fig. 3. This was taken at the edge of a hole, approximately 0.062 in. in diameter, drilled in Alcan 75S-T rod. The difficulty in properly backing-up such a surface by the usual method is readily apparent.

The technique was also investigated as an aid in the study of corroded specimens which usually have a considerable amount of corrosion product adhering to the surface which is crumbled and torn out during polishing. It was found that when this method was used, a great deal of this corrosion product could be retained for examination.

PREPARATION OF IRON POWDER COMPACTS AND POWDERS FOR MICROSCOPIC EXAMINATION

By H. M. JAMISON and E. S. BYRON*
Mellon Institute, Pittsburgh

ALTHOUGH many photomicrographs of iron powders and iron powder compacts have appeared in the literature, there has been relatively little information published regarding the procedures followed in the preparation of the specimens. Any metallographer, experienced in getting ferrous specimens ready for microscopic examination, can without doubt adjust his technique so as to prepare iron powders and iron powder compacts satisfactorily. A number of precautions, however, must be taken in the preparation of these samples, which may sometimes contain free graphite. These precautions can perhaps be explained best by describing procedures that have been found by the authors to give dependable results.

Iron Powder Compacts

Sampling and Sectioning — The choice of a representative sample of the material to be examined under the microscope is an extremely important consideration. It is generally advisable to prepare two sections of compacts; one should be in a plane parallel to the direction in which the pressure was applied. This view enables the technician to observe any irregularities, such as laminations, caused by faulty powder or by improper pressing or sintering conditions. The other section should be in a plane perpendicular to the direction of compact-forming pressure, which will permit a study of the effects of cold working on the powders during the pressing operation and of recrystallization during the subsequent sintering operation.

After the sample has been chosen, cut through it in the desired direction with a hacksaw and file the exposed surface to remove rough edges and obtain a flat face so the specimen will set upright in the mold if necessary to so mount.

Mounting — It is sometimes desirable to mount the specimen in a resinous material, such as lucite, bakelite, Tenite, or Transoptic. Lucite has the advantage of being completely transparent and crystal clear (when properly molded), thus exposing the entire mounted specimen to view from all sides and providing a ready means of permanently

*At the time the information presented in this paper was gathered, Mr. Jamison was research assistant on the multiple fellowship sustained at Mellon Institute by the Plastic Metals Division of The National Radiator Co.; he is now research engineer for Plastic Metals at Johnstown, Pa. Mr. Byron was also senior fellow on the same multiple fellowship, but is now section research engineer in the Molybdenum Development Division of Westinghouse Electric Corp., Bloomfield, N. J.

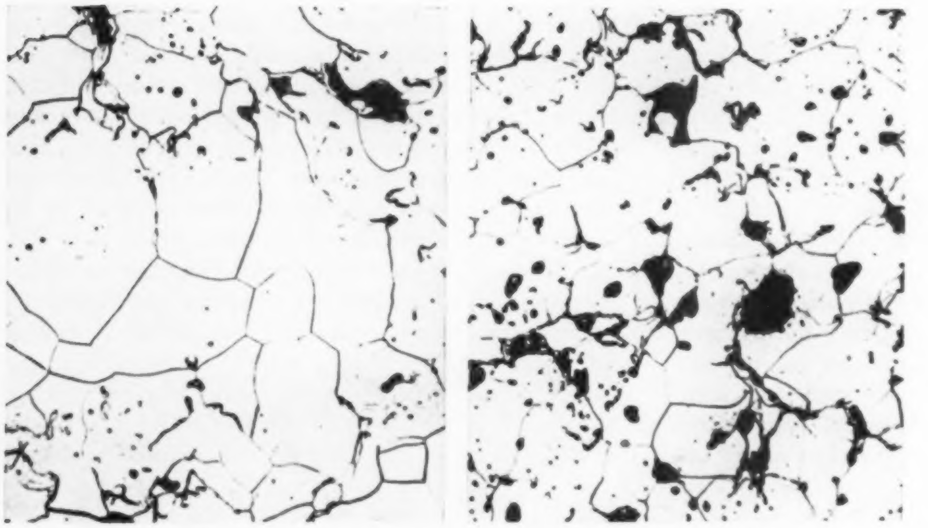
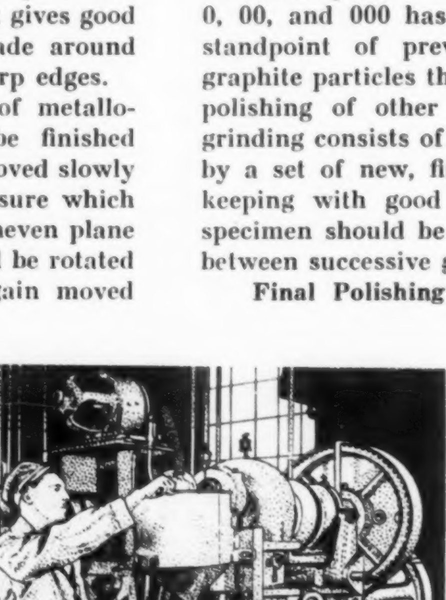


Fig. 1 and 2 — Sintered Iron Powder Compacts, Polished and Etched With 2% Nital and Magnified 500 ×. Electrolytic iron powder used in left compact; sponge iron powder used in right

identifying the specimen by a number, placed on the side of the section, or on a card incorporated in the mount. Details of the mounting procedure are the same as for any other type of metallographic specimen.

Rough Grinding — The exposed surface of the mount first should be made plane by a belt grinder. A No. 240 fine-grain sand belt gives good results. A small bevel should be made around both ends of the mount to remove sharp edges.

Just as in grinding other types of metallographic specimens, the surface to be finished should be placed against the belt and moved slowly back and forth. Avoid excessive pressure which will ruin the mount, resulting in an uneven plane across the specimen. The mount should be rotated 90° from its original position and again moved slowly backward and forward across the abrasive belt.



Every precaution should be taken to prevent the metal specimen from becoming too hot in the mount, as the heat will flow the resin across the metal specimen, or the mount may be cracked by the expansion of the metal. Test frequently by touching the finger to the metal specimen. The specimen may be dipped into water repeatedly during the grinding operation.

Although a disturbed condition (flow of metal) of the extreme surface cannot be prevented entirely during rough grinding, it can be minimized by proper technique.

When the specimen appears to be flat from center to edges and the grinding has removed all major surface imperfections, the rough grinding operation may be considered complete. The specimen, as well as the technician's hands, now should be washed *thoroughly* to prevent carrying over of particles of coarse grit from the rough grinding belt onto the first polishing paper. The surface of the mount should be washed with soap and water, using a small camel-hair brush, and dried with soft, absorbent paper.

Intermediate Grinding — The mount is now ready for the polishing papers. It is always advisable to use a new paper when beginning work on a new set of samples. Worn, dirty emery papers should be avoided, because the dull grit on them will promote distortion of the surface metal. Grinding by hand on polishing papers in the order 0, 00, and 000 has given best results from the standpoint of preventing dislodgment of any graphite particles that may be present. As in the polishing of other specimens, the intermediate grinding consists of replacing one set of scratches by a set of new, finer ones at right angles. In keeping with good metallographic practice, the specimen should be washed with soap and water between successive grinding operations.

Final Polishing — Because considerable difficulty may be encountered during the polishing of powder compacts by the usual methods, particularly with the retention of graphite particles, it is necessary to conduct the final polishing according to a special technique. Although particles may be dislodged during grinding, this is more likely to occur during final polishing. A Fisher "Gamal" cloth is recommended for final polishing. Experience has shown further that a

polishing abrasive made of chromic oxide has less tendency to drag out soft particles and will produce, in this operation, a higher luster on the polished surface than will an abrasive made of levigated alumina.*

The recommended abrasive may be prepared in the following manner: Weigh 50 g. of chromic oxide into a large bottle, add 1000 cc. of water, and shake well. Add 15 to 20 drops of a 10% gum arabic solution to the suspension, shake well, and allow to settle for 5 min. Decant the top 500 cc. into a flask; add three or four drops of 10% Aerosol to the decanted top portion and shake well. This suspension is now ready for use. More suspension can be made by adding 500 cc. of water to the 500 cc. of suspension left in the large bottle and repeating the procedure described above. As many as six batches of satisfactory polishing abrasive can be made from the original 50 g. of chromic oxide.

During the final polishing operation it is essential that the Gamal cloth be kept damp, but not wet, and that polishing of the surface proceed in only one direction. The mount should be grasped firmly and, by applying a slight pressure, held on the surface of the polishing wheel rotating at 550 r.p.m. While polishing, the mount should be moved continuously, in and out, in a radial direction to about 1 in. from the center of the wheel. When the scratches have started to become faint, the mount should be washed with soap and water, dried with a clean paper tissue, and etched. After etching, it should be placed back on the wheel for repolishing. Normally the specimen must be etched and repolished three times before it appears to be scratch-free.

Polishing should not be continued, under any circumstances, beyond that point required to just remove the scratches. In accord with good metallographic technique, the surface should be examined at frequent intervals and polishing discontinued when it first appears to be scratch-free. In the final stages the specimen may be rotated counter to the rotation of the wheel in order to prevent formation of "comet tails". During final polishing, it is essential that the specimen be held in contact with the revolving cloth under very lightly applied pressure. Any excessive pressure will ultimately dislodge the graphite that is present.

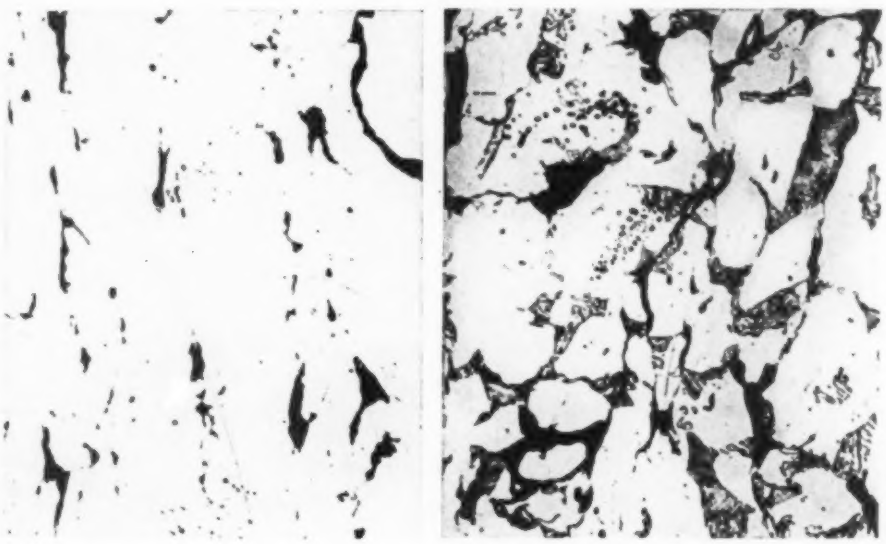


Fig. 3 and 4 — Sintered Compact Prepared From Electrolytic Iron Powder Mixed With Graphite, Unetched and Etched With 4% Picral, Respectively. 500 ×

Finally, the specimen should be washed with soap and water to remove any chromic oxide remaining on the surface, then washed quickly with ethyl alcohol and dried in a stream of air. The surface now should appear to be scratch-free upon examination at 100 diameters. The specimen may be etched directly after polishing or may be stored unetched for future use. In either case, the surface should be protected from oxidation and tarnishing in a desiccator or in a Buehler specimen cabinet.

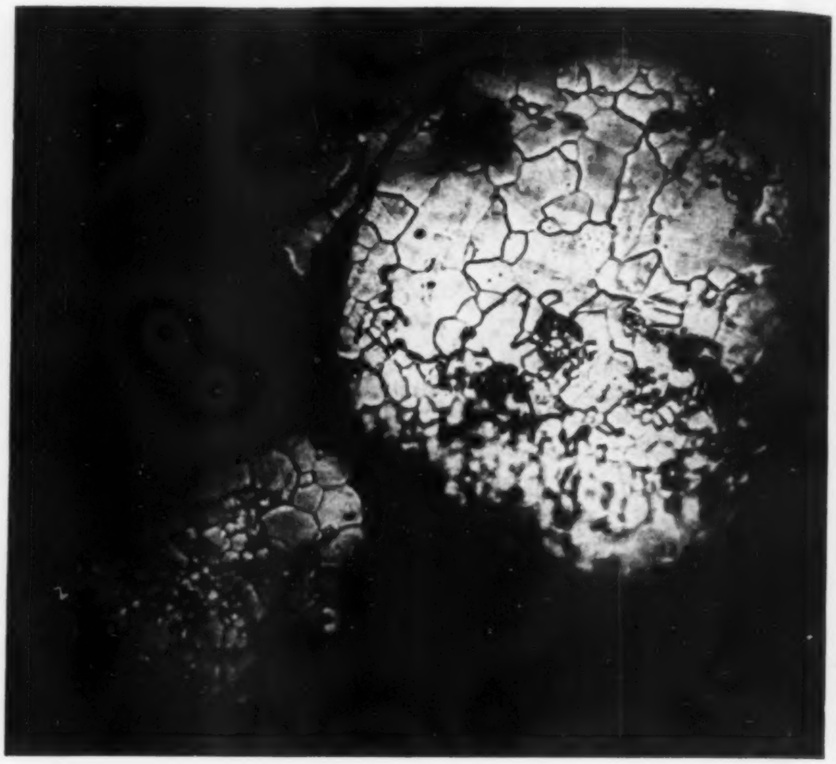
Photomicrographs of powder compacts prepared as described are shown in Fig. 1 to 4. Figures 1 and 2 contrast the structure of compacts prepared from electrolytic iron powder and from a reduced oxide type of iron powder. Photomicrographs of a compact, unetched and etched, prepared from electrolytic iron powder mixed with 2% graphite are reproduced in Fig. 3 and 4. This compact was purposely prepared and sintered so as to retain free graphite.

Iron Powders

A satisfactory procedure for the preparation of iron powder particles for microscopic examination is essentially the same as that described for

*For technique see "Rapid Hand Polishing of Micro Specimens" by Anton L. Schaeffler, *Metal Progress*, August 1944, p. 285.

Fig. 5 — Electrolytic Iron Powder at 500 ×, Polished and Etched With 2% Nital



iron powder compacts. The main differences between the two procedures are as follows:

Sampling — In sampling iron powders, extreme care must be exercised to procure a representative sample. They should be sampled in accordance with the standard procedure adopted by the Metal Powder Association.* A half-gram sample is sufficient where a 1-in. diameter mold is used for mounting.

Mounting — In order to polish powder samples satisfactorily, they must be set in a clear thermoplastic such as lucite. The latter should be ground to approximately the same mesh size as the powder to be examined and then mixed with it in the ratio of three parts of lucite to one part of iron powder by volume. The mixture should be poured into the cavity of the mounting mold and distributed in a uniform layer over the bottom plunger. Lucite powder (without mixture) then should be added to the proper level in the mold and the mounting continued in the usual way.

*"Tentative Method for Sampling Finished Lots of Metal Powders", M.P.A. Standard 1-45T; issued June 1945; Metal Powder Association, 420 Lexington Ave., New York City 17.

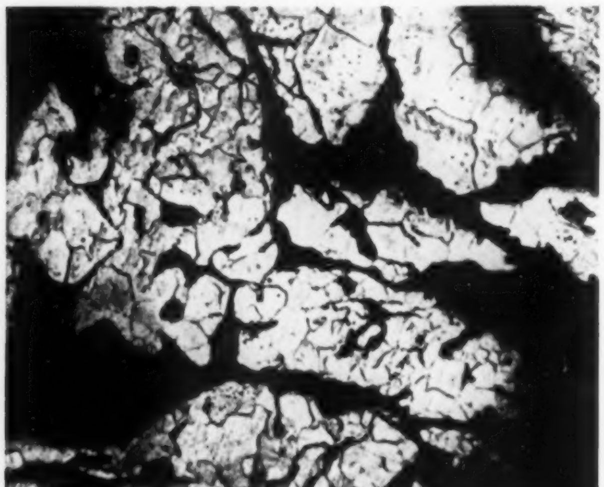


Fig. 6 — Sponge Iron Powder (Reduced Oxide) Magnified 500 ×. Polished and Etched With 2% Nital

Grinding and Polishing — In grinding specimens, the rough grinding procedure should be omitted and the samples taken directly to the first polishing paper. The balance of the procedure described for compacts should be followed with the exception of the inspections. Because of the relatively small size of the individual powder particles, the grinding scratches on them cannot be seen with the naked eye and it is therefore necessary to make these examinations at 100 diameters.

Photomicrographs of Powder — Photomicrographs, showing the structures of particles of electrolytic iron and sponge iron powders, prepared in accordance with this procedure, are presented in Fig. 5 and 6.

Acknowledgment — The authors wish to express their appreciation to E. W. Kempton, Jr., their associate at Mellon Institute, for making the photomicrographs and to the Homestead metallurgical laboratory of the Carnegie-Illinois Steel Corp. for suggesting the chromic oxide polishing abrasive.

The iron powders were minus 100-mesh annealed "Plast-Iron" and minus 100-mesh annealed "Plast-Sponge", supplied by the Plastic Metals Division of The National Radiator Co., Johnstown, Pa. Plast-Iron powder is produced by electrodeposition, and Plast-Sponge powder is a reduced oxide type.

Why NICKEL Alloy Steels Are Specified for Giant Generator Shafts

Alloy steel containing two and a half percent Nickel along with small percentages of other alloying elements give the heavy sections of this turbine rotor shaft the strength, toughness and endurance so vital to dependable performance. A yield strength of 80,000 p.s.i. combined with reduction of area consistently exceeding 36% in both radial and transverse directions was achieved in this heavy section.

PHOTO COURTESY OF GENERAL ELECTRIC CO.

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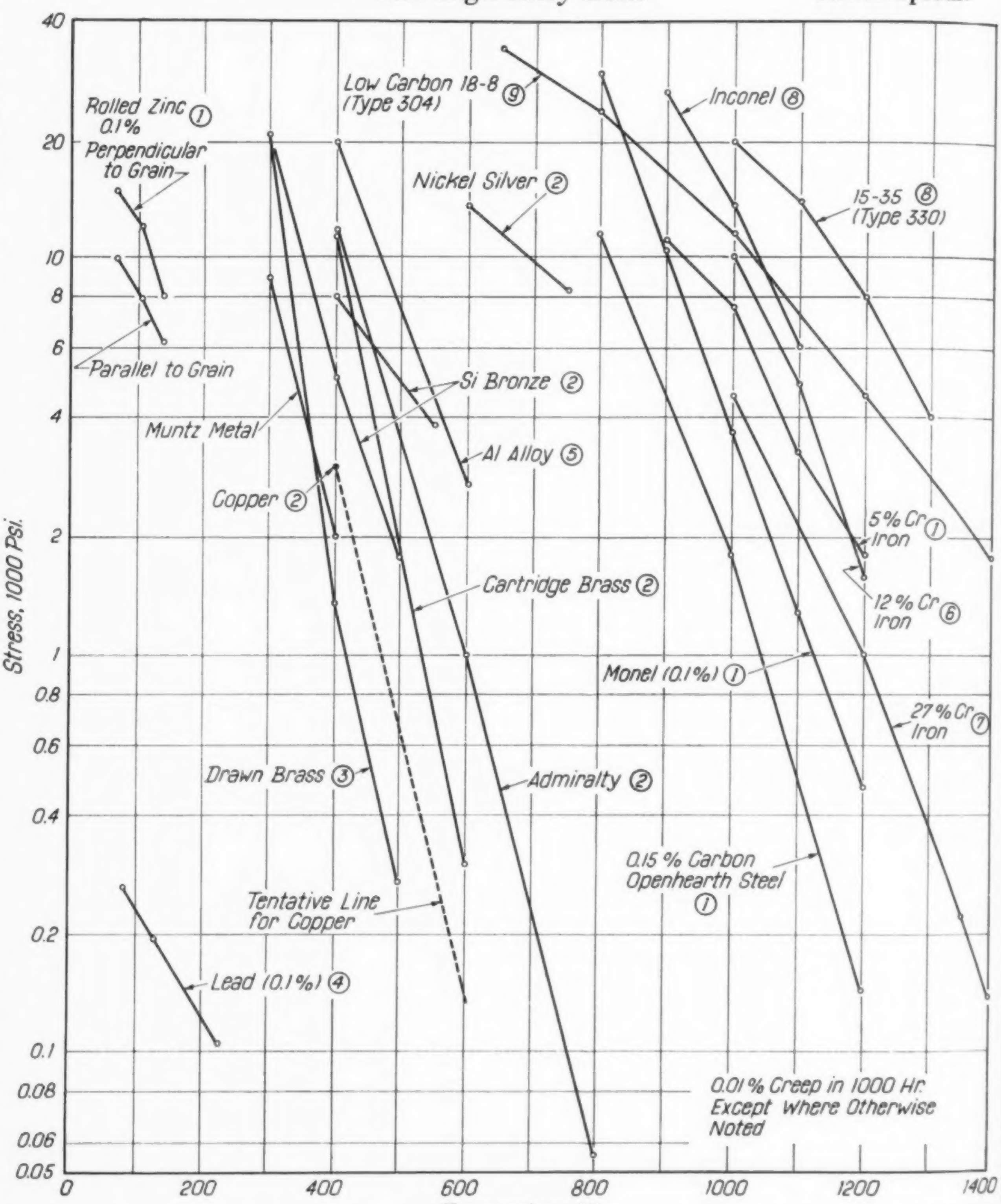
Creep Data for Nonferrous Metals

and High Alloy Irons

Kelvin Sproule



References:

1 — National Bureau of Standards Circular C447; 2 — "Copper and Copper Base Alloys", by Wilkins and Bunn; 3 — *Proceedings* of the American Society for Testing Materials, V. 42, p. 672; 4 — *Transactions* of the American Institute of Mining and Metallurgical Engineers, V. 143, p. 166; 5 — *Proceedings* of the American Society for Testing Materials, V. 35, p. 223; 6 — Pamphlet by Rustless Iron & Steel Corp.; 7 — H. D. Newell, *Metal Progress* Data Sheet (1946) No. 95; 8 — C. T. Evans, Jr., *Metal Progress* Data Sheet (1946) No. 97; 9 — C. T. Evans, Jr., *Metal Progress* Data Sheet (1946) No. 98.

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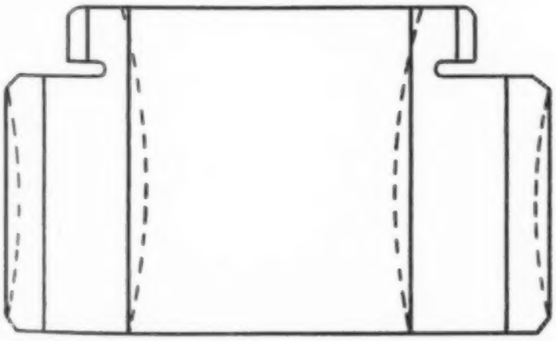
BITS AND PIECES

Reducing Distortion in Case-hardened Nickel-Chromium Gears

A FAIRLY heavily sectioned gear, manufactured from casehardened nickel-chromium steel of the S.A.E. 3312 type, was found to be severely distorted after heat treatment. The operations were normal for this class of steel — namely, carburize at 1635° F., slow cool, refine at 1560° F., quench in oil and harden at 1400° F., quench in oil. The gears had contracted in the bore with the outside diameter following the same contour, as shown exaggerated in the sketch (half actual size). The contraction of the bore was small at the outside edges, being −0.006 in. at one end and zero at the other, with a maximum contraction of −0.028 in. at the center. The maximum contraction of the outside diameter was much smaller, averaging −0.012 in. at the center. The ovality of the bore was 0.003 in.



The bore had to be ground, with resultant increase in time for removing excess metal and increase in wear of grinding wheels. Various methods were attempted to decrease the distortion but the only successful one was replacing the oil quench from the refining heat, by a cooling in air. The sequence then was:

Carburize the gear at 1635° F., slow cool, refine at 1560° F., cool in air, and harden at 1400° F., (quenching in oil). The distortion after this treatment was a maximum contraction of −0.006 in. in the center of the bore with little or no contraction of the outside diameter.

The only doubt which arose after this treatment was whether the desired physical properties would be obtained. A series of tests was carried out with the following results:

	Original Treatment	Revised Treatment
Tensile strength	189,500 psi.	193,000 psi.
Elongation	18%	18%
Impact	36, 34, 34 ft-lb.	33, 34, 34 ft-lb.

It will be seen from the results that the properties are in no way impaired by cooling the gears in air from the refining heat. (C. A. E. Wilkins, Bellshill, Scotland)

Predicting Creep Strength of Metals

THE QUESTION was recently asked: "What is the creep strength of electrolytic tough pitch copper at 600° F.?" The only available data on creep of copper at elevated temperature showed a strength of 3100 psi. at 400° F. for an elongation of 0.01% per 1000 hr. After construction of a chart (reproduced as the data sheet on page 440-B) containing information available to the author for other nonferrous metals, a creep strength was predicted of roughly 100 to 200 psi. at 600° F. for an elongation of 0.01% per 1000 hr., by merely drawing the dotted line from the one known value parallel to the trend for the copper alloys.

While creep data, in the form of stress versus rate-of-strain curves, are commonly plotted on log-log paper to yield straight lines, it is perhaps not so well known that stress and temperature

(for any designated rate of strain) plot in approximately straight lines on semi-log paper, and that the stress-temperature curves of many of the common metals and alloys are sufficiently parallel when plotted in this way that creep properties at various temperatures can be roughly estimated (provided that creep data on the metal in question are available at one other temperature).

The representative curves in the data sheet, taken from the literature, show a parallelism which is striking in view of the widely varying character of the metals. (KELVIN SPROULE, research metallurgist, International Nickel Co. of Canada, Ltd.)

Heat Treating Schedules

MANY scheduling problems are connected with the heat treatment of the various light aluminum alloys used in aircraft production, since the *time* at temperature is not a constant. However, this matter has recently been corrected by adopting alternative time cycles that are satisfactory for at least four important alloys: 53S, alclad 14S, R301 and 61S, and which conform to governmental specifications.

Under the old method 14S and R301 were aged together at 350° for 6 hr., while 53S and 61S were aged together at 350° for 8 hr. This resulted in a delay on rush jobs; due to the difference in time it was necessary either to hold 14S and R301 for 6 hr. while the furnace was being used to age 53S and 61S, or to use an engine-mount furnace, rivet furnace, or wood shop furnace for heat treating some of these alloys.

Under the new method the four alloys are all aged together at 350° for 8 hr. or 340° for 10 hr. This saves at least 40 hr. of furnace time each week, and eliminates the need for using other furnaces — at the same time eliminating any delays in the heat treating of rivets and motor mounts. There is a small direct saving of additional loading, unloading, and transportation of alloys to different furnaces. Storage space is also saved, as it is unnecessary to rack up an accumulation of aluminum, waiting to be heat treated. The shop also benefits through more efficient planning when working materials that have the same heat treatment specifications.

Either of the time cycles has distinct advantages over the old method. The 8-hr. treatment at 350° permits us to age at least four different alloys in the same furnace load. The 10-hr. treatment at 340° permits the shop to age this material during the interval between 2nd and 1st shift; the 2nd shift can put it in the furnace, the heat can be run while no one is working, and the day shift can take it out. (J. EDWIN BURKHARDT, Glenn L. Martin Co.)

Spotting Iron Contamination on Stainless Surfaces

IT IS OFTEN necessary and desirable to determine the amount of free iron on the surface of stainless alloys, particularly when the service would rust the free iron, cause preferential attack, or contaminate the product. Many methods have been proposed and practiced for determining free

Comparison Views of Ferroxyl Paper Tests on Inconel Sheets Ground With 120-Grit Wheels, One Iron-Contaminated, One Clean

iron; among these may be mentioned the aceto-acetanilide method of Union Carbide and Carbon Corp., the agar-potassium ferro and ferricyanide solution, and warm salt water solution. All these have some disadvantages, particularly where a record is required and where inaccessible spaces or overhead areas must be examined.

During the war a great deal of ferroxyl paper in strips approximately 2 in. wide was used to determine the pinholes in nickel plating — particularly in work for the atom bomb project. We tried this paper on stainless steel surfaces and found that it responded beautifully to free iron. The test has the advantage of recording the free iron and of being accessible to almost any location. Ferroxyl paper can also be used to detect free iron on rolled surfaces of monel, Inconel, and nickel.

The test is very simply made by moistening the paper with iron-free water and pressing it against the surface to be examined. Five minutes is usually sufficient to show any free iron. Occasionally tiny areas of Turnbull's blue will appear on the paper when not exposed to any contacting surface; this is not troublesome and does not detract seriously from the use of ferroxyl paper for the test.

This paper may be obtained from Hanson-Van Winkle-Munning Co., Matawan, N. J. Photographs illustrating its use to detect free iron on a contaminated surface of Inconel are reproduced herewith. (M. A. Scheil, director of metallurgical research, A. O. Smith Corp.)

Cupping 27% Chromium-Iron

We have had an interesting time of it in cold drawing cups of 27% chromium-iron. These cups were used as the ends of X-ray tubes to bond to glass, and at one time had been machined from bar stock.

The plate material furnished us by the mill had a very coarse grain structure and broke when drawn. However, we were able to work out a cycle of annealing and water quenching so we could draw cups several diameters long. We also found it necessary to add a "push" operation on the face of the cup to overcome excessive thinning of the material as previous draw radii were carried up the cups. Aside from requiring extra operations and special annealing cycle, we experienced little difficulty. Gages ran from 0.079 to 0.125 in. Preheating was not required.

As a substantial amount of material was saved and only a light machining operation was necessary, the cost of tooling was amortized over a few thousand pieces. I might add that the fact that a material can be drawn in this way makes it easy to get special wall thicknesses and sizes which may not be obtainable from tubing — particularly when eventual use does not require pieces to be drawn to an uneconomical depth in relation to diameter.

We would be glad to know of similar requirements for cups of this material. (Carter C. Higgins, vice-president, Worcester Pressed Steel Co.)

On-the-Job Annealing

Many times during spinning operations, the metal becomes work hardened. To anneal a piece without a loss of production time, engineers at the East Pittsburgh Works of Westinghouse arranged a gas torch near the work. Control of the flame is by a foot pedal on the floor; only a pilot light burns until the operator pushes on the pedal, thus preventing burning the thin part being formed.

The Russian Plan for Atomic Control

LAST June the American delegates to the United Nations Atomic Energy Commission presented the American plan for the control of atomic energy. This was based on the so-called Acheson-Lilienthal report[1] and provided for an international authority to control all atomic matters, a system of vetoless inspection, a system of vetoless punishment of atomic violators, and pooling of atomic knowledge and destruction of existing atom bombs step-by-step as safeguards are established.

A few days later the Russian delegate said: "The United States proposals in their present form cannot be accepted in any way by the Soviet Union, either as a whole or in separate parts," and presented an alternative plan, outlined[2] as follows:

"The high contracting parties solemnly declare that they will forbid the production and use of a weapon based upon the use of atomic energy, and with this in view, take upon themselves the following obligations: *(a)* Not to use, in any circumstances, an atomic weapon; *(b)* to forbid the production and keeping of a weapon based upon the use of atomic energy; *(c)* to destroy all stocks of atomic energy weapons, whether in a finished or semi-finished condition."

After six months of discussion, the Atomic Energy Commission made its final report (Dec. 30) which embodied the American plan in all its essentials.[3] The vote in the Commission was 10 to 0, with Russia and Poland abstaining. It was then the responsibility of the Security Council to translate the principles laid down in the Commission's report into practical measures.

At the meeting of the Security Council on Feb. 14, ANDREI GROMYKO, the Russian delegate, read a lengthy criticism of the Atomic Energy Commission's report in which he said: "The proposals of the United States do not provide for the immediate prohibition of atomic weapons; it depends on a preliminary establishment of a broad system of international control. Yet the *prohibition* of atomic weapons should not stop the working out of the measures for atomic energy control. . . . [The exclusion of atomic affairs from the provisions of the veto] means that somebody has certain plans which are not in conformity with the decision adopted by the General Assembly . . . . undermines the foundation of the effective activities of the Security Council . . . . sows seeds of suspicion toward the great powers, and assumes that the great powers first of all might be violators of the control." He also pointed out that only the Security Council—not any Commission—has power to punish violations, but it "must take such measures in accordance with the Charter. . . . In spite of the serious defects of the report I am prepared to consider it item by item and to submit appropriate amendments" [which are briefly as follows]:[4]

Add to ¶ 2: "Inspection, supervision and management on the part of an international organ are applied in regard to all existing plants for the production of final atomic materials (nuclear fuel) immediately after an appropriate convention is put into effect" [that is, not to be delayed by the step-by-step process].

Substitute for the first sentence of ¶ 5: "That an effective system of control of atomic energy must be international in scope and must be established by an enforceable multilateral convention which must be administered within the framework of the Security Council" [thus enabling any permanent member to exercise a veto].

In ¶ 6, eliminate the words "An international convention, if standing alone, would fail" in its purposes.

A new, much shorter and less precise ¶ 3*(a)*,[5] but one which re-emphasizes the paramount control of the Security Council: "Establishing within the framework of the Security Council an International Control Commission, possessing powers and charged with responsibility necessary for effective administration of the terms of the convention and for the prompt carrying out of its day-to-day duties. Its rights, powers and responsibilities should be clearly established and sufficiently broad to enable the Commission to deal with the situation that may arise in connection with new discoveries. In particular, the Commission shall render every kind of assistance for extending among all nations the exchange of basic scientific information on the use of atomic energy for peaceful purposes, shall be responsible for preventing the use of atomic energy for military purposes, and for stimulating its uses for the benefit of the people of all nations. The control organs and the organs of inspection should exercise their control and inspection functions, acting on the basis of their own rules, which should provide for the adoption of decisions by the majority."

¶ 3*(c)*. Change the last phrase "by all persons under their jurisdiction" to read "by all their nationals".

¶ 3*(d)*. Change to read: "Providing for destruction of stocks of manufactured atomic weapons and of unfinished atomic weapons."

¶ 3*(e)*. Strike out the last sentence [which prohibits the veto].

¶ 5. Substitute for the first sentence: "The convention should embrace the entire program for putting the system of international control of atomic energy into effect and should provide a schedule for the completion of the transitional process, after the expiration of a certain period of time, step-by-step in an orderly and agreed sequence leading to the full and effective establishment of international control of atomic energy."

[1]Outlined in *Metal Progress* for May 1946. [2]*Metal Progress*, July 1946. [3]Outlined in *Metal Progress* for January 1947. [4]Their import can be appraised by comparing them with the corresponding paragraphs of the original; see *Metal Progress*, January 1947, p. 89 and 90. [5]January issue, p. 90.

Study of 171 heats of 18-8 electrode wire showed that to avoid root cracks in weld metal the chromium must be at least twice the nickel, and the carbon and the phosphorus both at practicable minimums. Nitrogen induces crack sensitivity in weld metal from higher alloy (25-12).

CHEMICAL COMPOSITION OF AUSTENITIC WELDING ELECTRODES

By RICHARD K. LEE
Metallurgical Engineer, The McKay Co., York, Pa.

AN ARTICLE by R. David Thomas, Jr., in *Metal Progress* last September discussed the "Crack Sensitivity of Chromium-Nickel Stainless Weld Metal". While we cannot agree with all the statements in that article, especially as regards the influence of certain weld-rod coatings — as may be judged by the letter published last month in the correspondence pages of this magazine — there is no point in shutting our eyes to the importance of the general problem, still unsolved.

The purpose of this present brief communication is to present some facts gained from a statistical study of 171 heats of A.I.S.I. Types 307* and 308 steel core wire furnished to us in 1944. (See Table I.) The steel was used to manufacture the manganese modified 19-9 electrodes for welding armor. In the Type 308 core wire, sufficient manganese was added to the coating to result in the required content of the manganese in the weld metal. All of the weld rods from these heats were coated with the lime type of covering.

One of the first correlations made was of cracking sensitivity of the weld metal from the 308 core wire with manganese added, and the weld metal from the 307 core wire. No difference could be found. Furthermore, a comparison of steels of the same grades from each of three alloy steel producers failed to show any differences in crack susceptibility due to difference in the source.

*Steel 307 is not a "standard stainless steel" on the latest list of the American Iron and Steel Institute.

Table I — Chemical Specifications of Heats Studied

Element	Type 307* McKay	Type 308 A.I.S.I.	Type 308 McKay
Carbon	0.12 max.	0.08 max.	0.12 max.
Silicon	0.60 max.	1.00 max.	0.60 max.
Manganese	3.75/ 4.75	2.00 max.	1.5/ 2.0
Chromium	19.5 /22.0	19 to 21	19.5/22.0
Nickel	9.5 /10.5	10 to 12	9.5/10.5
Titanium	0.40 min.		

*Not an A.I.S.I. "standard".

At the time this statistical study was made we were not aware of the arbitrary formula connecting microstructure and chemical composition developed by F. K. Bloom of the Rustless Iron and Steel Division of Armco and reproduced by Mr. Thomas in his paper. In the absence of such knowledge we correlated the pertinent data of the 171 heats by grouping them as shown in Tables II to V. In these tables we used a "cracking index" for each heat, an arbitrary number derived from the amount of extra alloy required to be added to the core wire to prevent root bead cracking. The bead cracking susceptibility, therefore, increases with increasing indices.

All chemical data are based on analysis of core wire rather than weld metal.

The data in Table II, page 446, clearly demonstrate the primary requirement for this material. That is, an absolute minimum of twice as much chromium as nickel is required. This minimum ratio ($Cr/Ni > 2.0$) was specified by both the Army and the Navy for these electrodes.

In Table III a coincidental feature is shown: As the carbon

content increases from a practicable minimum, the phosphorus content also increases — apparently a function of steel melting practice and control. The average chromium-to-nickel ratios are practically constant throughout this grouping, being 2.09 to 2.13 in the extremes. To us, these data show a very pronounced second-order effect, in that the crack susceptibility increases with the combined increases of carbon and phosphorus, while the chromium-to-nickel ratio remains constant.

Table IV, based on increasing phosphorus content, shows the same general tendency toward greater cracking susceptibility as indicated for carbon in Table III — as would indeed be expected from a study of Table III. The correlation is not as pronounced as in the carbon grouping, nor do the carbon contents follow along with the phosphorus contents as regularly as in Table III; perhaps that is because the phosphorus is held to a very low and narrow range in all but 16 of the heats. This element is commonly regarded as a "bad actor" in austenitic weld metal.

Table V again illustrates the effectiveness of the chromium-to-nickel ratio, with secondary effects from carbon and phosphorus on the crack sensitivity of the weld metal. As the cracking index goes up, the chromium-nickel ratio comes steadily down.

Several other arrangements of the data of this study were made, but no correlations could be found except those already noted.

The foregoing discussion, although based entirely on lime-coated electrodes for welding armor, has been found very helpful in evaluating stainless electrodes for peacetime welding applications. We have been able to use this information for titania coated electrodes as well as for those with lime coverings.

Finally, we have learned that nitrogen, an element which is rarely determined in the chemical analysis of stainless steel, has quite profound effects on bead crack sensitivity. For example, A.I.S.I. Type 309 (25-12) has been very

(Continued on bottom of next page)

Table II — Groups of Heats Arranged in Order of Increasing Cr/Ni Ratios

Cr/Ni Ratio Group	Number of Heats	Average Content of Element					Cracking Index
		C	P	S	Cr	Ni	
1.93 to 2.02	15	0.105	0.0187	0.0131	20.35	10.22	106.0
2.03 to 2.04	16	0.117	0.0206	0.0112	20.32	9.96	110.0
2.05 to 2.07	23	0.113	0.0205	0.0113	20.52	9.94	103.5
2.08 to 2.09	24	0.112	0.0214	0.0119	20.65	9.90	96.2
2.10 to 2.11	16	0.118	0.0208	0.0105	20.64	9.80	91.9
2.12 to 2.13	22	0.113	0.0210	0.0109	20.75	9.79	96.4
2.14 to 2.16	25	0.102	0.0196	0.0130	20.81	9.69	73.2
2.17 to 2.20	15	0.101	0.0203	0.0117	20.91	9.58	63.3
2.21 to 2.50	15	0.107	0.0196	0.0123	21.28	9.36	48.0

Table III — Groups of Heats Arranged in Order of Increasing Carbon Contents

Carbon Group	Number of Heats	Average Content of Element				Cr/Ni	Cracking Index
		P	S	Cr	Ni		
0.05 to 0.07	16	0.0170	0.0107	20.70	9.78	2.12	65
0.08 to 0.09	29	0.0193	0.0114	20.53	9.68	2.12	67
0.10	16	0.0195	0.0132	20.68	9.80	2.12	69
0.11	19	0.0211	0.0128	20.88	9.58	2.13	75
0.12	42	0.0201	0.0107	20.77	9.92	2.09	98
0.13	28	0.0214	0.0118	20.68	9.84	2.10	90
0.14 to 0.15	21	0.0233	0.0132	20.59	9.74	2.12	135

Table IV — Groups of Heats Arranged in Order of Increasing Phosphorus Contents

Phosphorus Group	Number of Heats	Average Content of Element				Cr/Ni	Cracking Index
		C	S	Cr	Ni		
0.010 to 0.015	21	0.0862	0.0112	20.64	9.89	2.09	77.1
0.016 to 0.017	18	0.106	0.0132	20.72	9.72	2.13	86.1
0.018 to 0.019	33	0.112	0.0111	20.88	9.90	2.11	87.0
0.020	40	0.114	0.0120	20.70	9.82	2.11	82.3
0.021 to 0.022	17	0.114	0.0120	20.49	9.68	2.12	99.4
0.023 to 0.025	26	0.113	0.0113	20.72	9.76	2.12	87.8
0.026 to 0.042	16	0.124	0.0112	20.45	9.76	2.10	114.4

Table V — Groups of Heats Arranged in Order of Increasing Cracking Indices

Cracking Index	Number of Heats	Average Content of Element					Cr/Ni
		C	P	S	Cr	Ni	
0 to 50	25	0.0988	0.0197	0.0210	21.06	9.66	2.18
60	37	0.0951	0.0192	0.0110	20.75	9.73	2.14
70 to 80	36	0.0858	0.0196	0.0114	20.69	9.84	2.10
90 to 100	26	0.116	0.0218	0.0119	20.57	9.85	2.09
110 to 120	22	0.115	0.0211	0.0139	20.49	9.93	2.06
140 to 180	25	0.131	0.0216	0.0113	20.53	9.86	2.08

Wartime use in France of slagging gas producer for melting foundry iron — in effect a closed top shaft furnace with hot blast — surmounted shortages of good metallurgical coke. Products are a high-strength iron and surplus gas for other necessary heating operations. Its further utility is suggested for producing hot metal for rapid refining in open-hearth or electric furnaces.

SLAGGING GAS PRODUCER FOR MELTING FOUNDRY IRON

By H. LaPLANCHE
Chief Metallurgist and Chemist, Citroen Works, Clichy, France

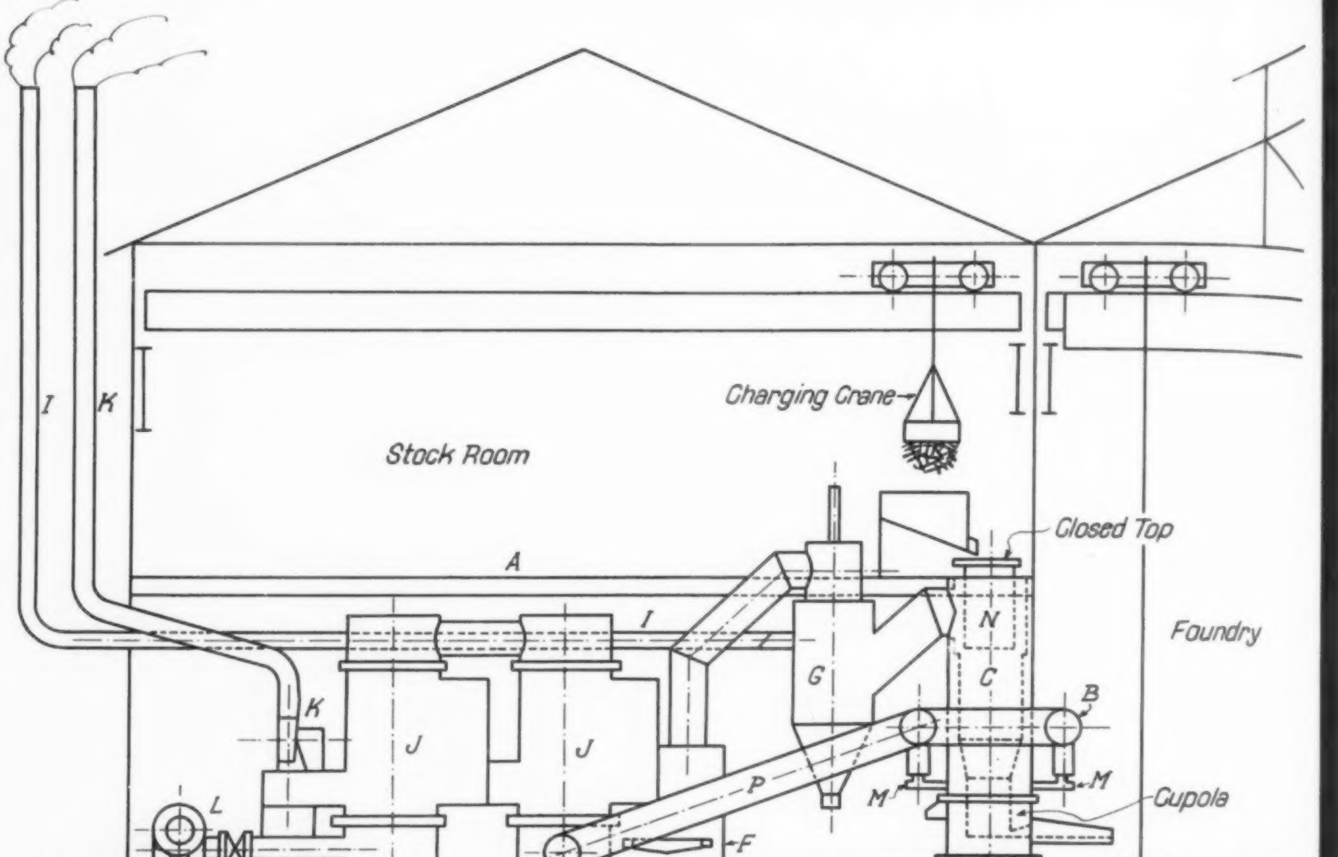
THE FIRST "slagging gas producers" in France, blown by preheated air, were installed in 1925 by the Société des Houillères at St. Etienne, Loire. This Achille plant, described in *Revue de l'Industrie Minérale* for March 1934, consisted of two gas producers, each capable of gasifying and slagging 100 tons daily of a mixture of high-ash combustibles plus limestone flux. This installation has operated without interruption from 1925 to 1935. With a single gas producer in operation approximately 200,000 cu.m. of gas of 1275 cal. was produced every 24 hr. (7,000,000 cu.ft. of gas of 143 B.t.u. per cu.ft.). This gas was used for glass melting. The glass plant and the gas producers were abandoned in 1935, when the company which was using the gas decided to concentrate its operations in the north of France.

Several years after these processes had been initiated, slagging gas producers for the smelting of fine nonferrous scrap and dross were promoted by the company known as La Vieille Montagne for recovery of values from various minerals and residues containing principally zinc, copper, lead, and the precious metals gold and silver. In a paper before the International Mining Congress (1935) Van Oirbeek described the results obtained in several Belgian and French plants.

This equipment, which has functioned without interruption since its installation, treats daily 200 to 300 tons of mixed combustibles and various residues of the zinc electrolysis, residues from zinc furnaces, skimmings from lead furnaces, and the like. Treatment is similar to the action of a conventional blast furnace in that the copper, gold and silver are concentrated in a matte which is drained off with the slag and separated by virtue of their mutual immiscibility and different densities in a forehearth. The top gas is also analogous to blast furnace gas and carries the volatile products. In this respect the operation is different from the conventional blast furnace for smelting lead or copper; the latter, being quite open around the charge door at the top, permits all the CO and H_2 in the top gases to burn immediately. By cooling, filtering or passing through electrostatic precipitators the zinc and lead fumes are recovered as oxides with high metallic content (65 to 70%).

WELDING ELECTRODES

difficult for the steel mills to process into core wire for the electrode manufacturers. Working in cooperation with two alloy steel mills we have tested for crack sensitivity three experimental heats of this material (25 Cr, 12 Ni) to which small additions of nitrogen had been deliberately made. The nitrogen addition markedly improved the hot working properties of the steel in the producers' mills. However, it increased the cracking propensities of the weld metal to such an extent that it was impossible to use the steel as electrode core wire. In all three heats the composition of the steel was normal for the grade, except for the nitrogen addition.



Gas-Producer Cupola, Stoves and Auxiliaries for Melting Foundry Iron

Electrolysis of these oxides in sulphate solution gives high-purity zinc metal cathodes and lead sulphate sludge. The cleaned gases are sometimes used to heat metallurgical furnaces; in one plant they are burned at high pressure in a central station generating electricity.

In 1936 an important installation of a similar smelting gas producer was erected in Norway at the Det Norske Zinkkompani. This equipment, with a capacity of 300 tons per day, also treats briquetted sludges from electrolytic refineries.

At about the same period an installation, including a 50-ton gas producer, was built by the Société Francaise des Métaux et Alliages Blancs at St. Denis, Seine, France. This equipment is used to refine various wastes, particularly slag and skimming from lead furnaces and pots for remelting bearings, bronzes and the like. These residues may contain up to 1% tin. In this installation the tin is volatilized to a sulphide, filtered, and then reduced to metal by electrolysis. Furthermore, a matte is produced which contains the copper originally in the slag being treated.

Use in Iron Founding — Recently the same type of equipment has been used in France and other countries, either for melting foundry iron or openhearth or electric furnace charges, or for the simultaneous production of both liquid iron and combustible gas. The device has been of particular value in wartime — and since — for its ability to operate with a minimum of metallurgical coke of good quality and a maximum of other carbonaceous fuels very high in ash and moisture. Fortunately the first of these special installations was completed in 1934 by the Société des Ateliers de Chaudronnerie et de Fonderie de St. Etienne, and its capabilities were demonstrated long before the war. It consists of a gas-producer cupola with a capacity of 3 tons per hr. A similar installation was completed in 1939 at Toulon by the Société de Matériel Naval du Midi.

This type of installation is shown in the diagram above. The materials to be charged (essentially scrap iron and steel, coke and coal, and limestone flux) are stocked on the working floor *A*, weighed, and then dumped into the charging bell *N* of the gas-producer cupola *C*. The cupola is lined with an alloy steel cylinder 5 ft. in interior diameter and 13 ft. total height. This cylinder is water cooled on its outside in order to reduce, if not eliminate entirely, wear resulting from fusion of the interior coating, which is automatically renewed by solidification of the molten slag. Height of the charge above the tuyeres is limited to 8 ft. The charge descends rapidly to the melting zone; cast iron runs into the ladle *E*;

the cupola is blown by means of a brick-lined bustle pipe and the water-cooled tuyeres *M*.

Top gases are normally sent through the dust catcher *G*, through the firebox *F*, to the two air preheaters *J*, *J*, and withdrawn by fan and discharged through the chimney *K*. Surplus gas can be sent to the core ovens. Emergency bleeder valves allow a rush of gas to discharge directly to air through pipe and chimney *I*, *I*. In starting up, or to supply a deficiency of heat, a fire grate *F* is attached to the leading preheater. A counter current of air starts with the blower *L*, passes through heaters *J* and *J* in series, thence to the cupola by main *P*, bustle *B* and tuyeres *M*, *M*.

Blowing hot air into a cupola greatly modifies the phenomena which take place in iron melting. As the temperature of the air is raised, the temperature of the charge increases, and the melting zone becomes more and more reducing in nature. For an air temperature of about 900° F. the temperature of the melt in the cupola will reach about 3300° F. (which temperature is limited to a short distance above the tuyeres). The heat developed in this zone is almost entirely concentrated in the molten material; above this zone the temperature decreases rapidly; at a level 6 ft. above the tuyeres it is only about 750° F. — lower than the temperature at the mouth of the ordinary foundry cupola.

Such a high-temperature reducing zone also enables the operator to burn retort coke, gas coke, anthracite, and other carbonaceous materials, provided they have a minimum of strength and calorific power.

The hot blast, gas-producer cupola gives the following advantages:

1. Its product is cast iron low in carbon, low in sulphur, and thoroughly deoxidized.

2. Its slag is low in iron oxide — often less than 2%. Loss of iron by burning, which is of the order of 5% in the ordinary cupola and reaches a much higher figure in the manufacture of semisteel, is therefore practically eliminated.

3. The hot, reducing, melting zone reduces part of the silicates in the ash; thus the iron charged is enriched in silicon. Likewise loss of manganese is considerably reduced.

4. The very high temperature attained at the tuyeres facilitates the melting of scrap steel without addition of ferrosilicon.

5. The rapid melting of the scrap, under the conditions outlined above, results in iron of low carbon content and high mechanical strength. Alloys (nickel and chromium) existing in the charge come through to the iron with much less loss than experienced in cold-air cupolas. Furthermore, since the iron is much hotter than that cast from the ordinary cupola, ferro-alloys may be added directly in the ladle.

6. Finally, it has been found that briquetted steel turnings can be readily melted in the hot blast cupola.

An average charge for the manufacture of high-strength foundry iron consists of 80 to 85% scrap iron and 20 to 15% of ferrosilicon (with 10% Si). Coke is from 15 to 18% of the iron, and limestone flux is one-third to one-half the weight of fuel, depending on its ash content.

Characteristics of the Cast Iron

Chemical Composition — Carbon content varies with three principal factors, namely, temperature of the hot air, proportion of coke, and speed of melting. Practically, carbon varies from 2.5 to 3.2%. It can be increased by prolonging the time of contact between the coke and the liquid iron in the melting zone.

Silicon varies from 0.2 to 0.5% when the charge consists entirely of scrap steel, without cast iron, pig, or ferro-alloys. Any desired silicon content can be obtained, without loss, by appropriate additions.

Manganese will be about that of the metal charged; it varies between 0.5 and 0.8%.

Phosphorus content depends on that in the scrap, and varies between 0.03 and 0.10%.

Microstructure — Fine, lamellar graphite, well distributed in a pearlitic matrix, characterizes the structure of these irons. The high melting temperature results in a homogeneous metal quite different from the semisteel obtained in an ordinary cupola.

Hardness — Representative Rockwell B hardness readings were taken along the entire length of a cylindrical test piece 1 in. in diameter and 15 in. long, cast vertically in baked sand. Readings were taken on a flat ¼ in. wide, lengthwise of the specimen, and were all either B-95 or 96. In depth they tapered to B-93 at the center.

Mechanical Characteristics — Shear strength measured on ¼-in. cylindrical specimens is 40,000 to 57,500 psi.

Impact test on bars 40x40x200 mm. (1.57x1.57x7.87 in.), knife edges spaced 6¼ in. apart: 80 to 120 cm. drop of 12-kg. tup (31 to 47 in. drop of 26½ lb. tup).

Static bend test on 10x8-mm. bars, 30 mm. distance between supports (0.39x0.31x1.18 in.): rupture at 1000 to 1400 kg. (2200 to 3100 lb.), deflection 0.22 to 0.33 mm. (0.009 to 0.013 in.).

Desulphurization — The gas-producer cupola melts metal at high temperatures in a reducing atmosphere and with a high lime slag — condi-

tions which are favorable to the production of desulphurized iron. (In this connection, the gas-producer cupola can also be used for second-grade irons.) Desulphurization is optimum when the proportion of limestone flux is increased so as to obtain a slag with about 40% CaO.

Simultaneous Production of Cast Iron and Heating Gas

An interesting application of the gas-producer cupola is in melting iron for openhearth furnaces and electric furnaces, and at the same time producing an excess of gas of fair thermal capacity. To the coke are added other combustibles with suitable strength. All the carbon charged is gasified, producing a fuel with a calorific value comparable to that of ordinary gas-producer gas. Injection of a controlled quantity of steam into the hot air blast will increase the calorific value of the top gas.

The following data were obtained in the plant described above:

The material charged consisted of *(a)* metallurgical coke of inferior quality containing 8% water and 15% ash, *(b)* a banded anthracite coal containing 10% volatile matter and 20% ash, *(c)* scrap iron. Composition of the charge was coke 20 parts, banded coal 65 parts, limestone flux 15 parts and scrap iron 100 parts. Each ton of this mixture contained 1160 lb. of fixed carbon. Total mixture charged per 24 hr. was 53 tons.

Operating data were as follows:

80,000 cu.ft. of air was blown per hr.; its temperature at the tuyeres was 1000° F.; 300 lb. of steam was supplied the reheaters each hour.

The total volume of gas produced was 115,000 cu.ft. per hr. of which 15% was consumed in the reheaters, leaving nearly 100,000 cu.ft. of gas available per hr. for other purposes. The composition of this gas averaged CO_2 3%, CO 29.2%, H_2 10.8%, CH_4 1.1% and N_2 56%. Its calorific value was 140 B.t.u. per cu.ft. — 1270 cal.

Slag fall amounted to 450 lb. per hr. Its composition was SiO_2 34.4%, Al_2O_3 11.5%, CaO 44.6% and FeO 1.8%.

Approximately 1000 kg. (2200 lb.) of cast iron was tapped per hr. Its composition was C 3.20%, Si 1.00%, S 0.06% and P 0.05 to 0.06%.

These results demonstrate the utility of the gas-producer cupola in melting iron for hot charges into an openhearth furnace producing a hot iron of low phosphorus content, which can be rapidly refined, and at the same time making a gas of good calorific value for use either in the openhearth furnace itself or in other necessary heating operations around the steel mill.

BOOK REVIEW

Talks About Steelmaking, by HARRY BREARLEY. 236 pages, 6x9 in., 14 illustrations, red cloth binding. Published by The American Society for Metals. Price, $3.50.

Brearley's ruminations based on a lifetime spent in steelworks make interesting reading. In addressing, as he puts it, sometimes "the man", sometimes "the boy", he speaks out boldly and takes issue at every turn with entrenched tradition. His approach to this subject is usually unorthodox — perhaps iconoclastic. Those who devote time to studies of, say, the effect of triaxial stresses or to exact determination of an elastic limit may find his approach to the testing of steels oversimplified almost to the *reductio ad absurdum*.

The book gives a short but colorful introduction to the pioneer melters of steel, Huntsman, Bessemer, Siemens and Thomas. While one may, as the author suggests, read the chapters in any order he cares to, the book follows a rather logical pattern from melting through casting, forging, testing to specification, and then has some closing chapters delving into the philosophy of working and the earning of money.

His italicized comment, "Good steel is steel that is excellent for the purpose for which it is made", has a familiar ring, but how many will agree with his methods of arriving at how to determine how excellent steel may be for any given purpose is problematic. Brearley discounts the value of elongation and reduction of area figures in a tensile test and rests his case for toughness on the Izod value. If he has any ideas concerning a limit of proportionality or elastic limit he makes no mention of them. He suggests that hardness, for evaluating strength, and an Izod test, to measure toughness, are all one needs.

This book, then, is not one in which to seek all the answers, but one in which one will find many questions posed and answered only in Brearley's way, and probably not often as convention would dictate nor as the reader would answer them. Some discussions seem incomplete, as the one in which pouring is dismissed with a development leading to bottom-casting, as though top-casting were unthinkable, though thousands of tons of steel "excellent for the purpose for which it is made" are poured daily in this manner.

The book is, all in all, stimulating, provocative, readable and informative and in no sense of the word heavy metallurgical reading. Indeed few can write as engagingly as Brearley uses the English language.

FRANCIS B. FOLEY

PERSONALS

Frank M. Cathcart, Jr., is associated as sales engineer with the Timken Roller Bearing Co. in the Denver territory.

James T. Kemp, formerly connected with various governmental agencies in the United States, England and Germany, including the Harriman Mission for Economic Affairs, has resumed his former work as a metallurgical engineer with the American Brass Co. in Waterbury.

Returning from service in the Navy, **W. C. Truckenmiller** has been appointed assistant professor of metal processing, University of Michigan.

Conrad Wissmann has accepted the position of metallurgist at Los Angeles Steel Casting Co., Los Angeles, Calif.

Robert S. Burpo, Jr., has resigned as associate editor of *Materials and Methods* to accept the appointment as assistant professor of Physics at Massachusetts State College, Amherst, Mass.

H. J. French, a past president of, has been appointed assistant vice-president of the International Nickel Co. of Canada, Ltd. Mr. French had been assistant manager of the development and research division since 1943. **O. B. J. Fraser**, for the past 13 years director of technical service and more recently head of the industrial chemicals section of the development and research division, has been appointed to the assistant managership of this division to succeed Mr. French. **William A. Mudge** has become director of the technical service section. **Donald J. Reese**, while continuing to head the iron and nonferrous casting section of the development and research division, will also be in charge of its field sections. **V. N. Krivobok** will head the stainless steels section and **T. N. Armstrong, Jr.,** the railway and cast steels section.

S. B. Knutson is now general superintendent of the Flexsteel Division of the National Electric Products Corp. at Ambridge, Pa., succeeding the late Earle B. Douglass. Mr. Knutson was formerly with the Standard Steel Spring Co.

C. E. Lacy, formerly at the research laboratory of the International Nickel Co., has joined the staff of the research laboratory, Hanford division, General Electric Co., Richland, Wash.

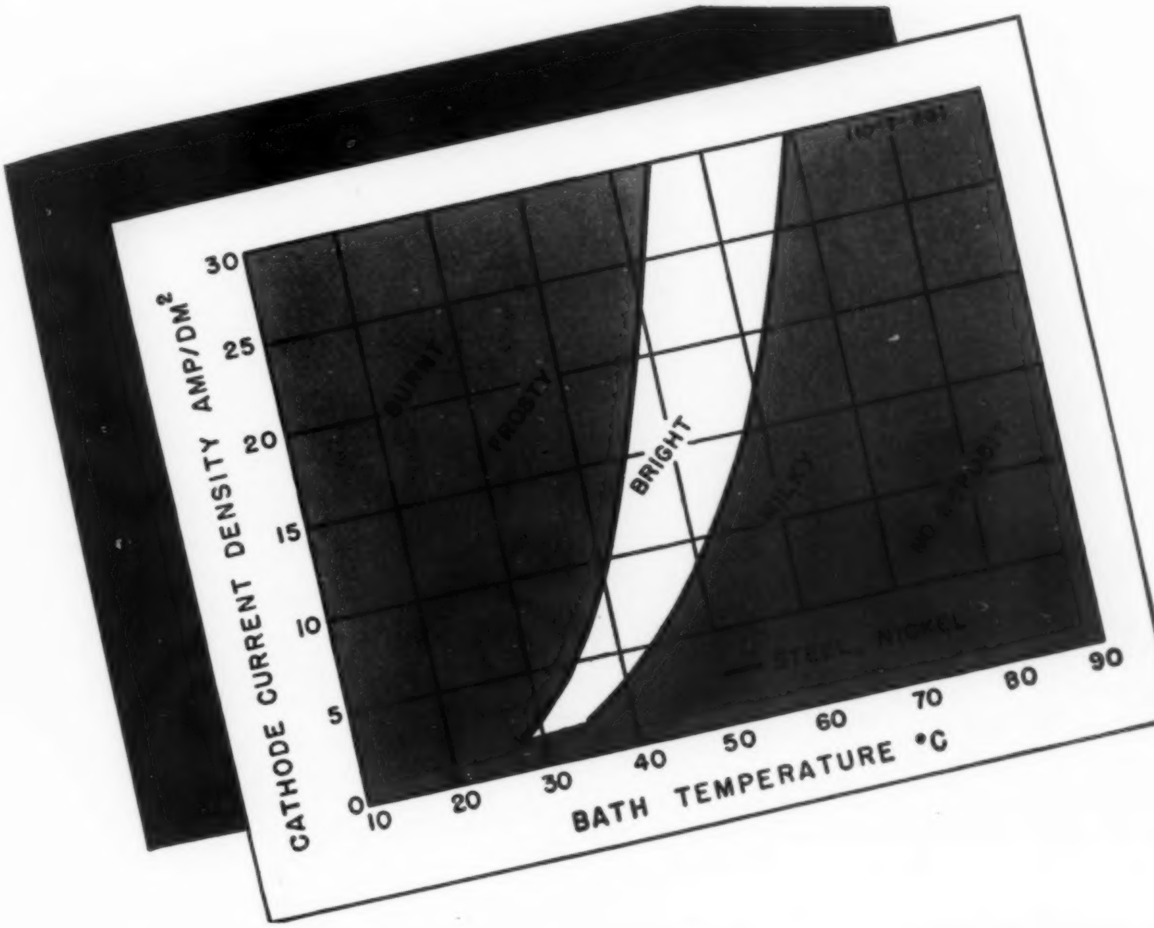
Charles K. Leeper, previously at the applied physics laboratory, Johns Hopkins University, is now engaged in research at the department of chemical engineering, Massachusetts Institute of Technology, while studying for his master's degree.

Lincoln S. Gifford is now plant engineer at the Signode Steel Strapping Co., Chicago, having resigned from a similar post with the Ingersoll Steel Division, Borg-Warner Corp., Kalamazoo, Mich.

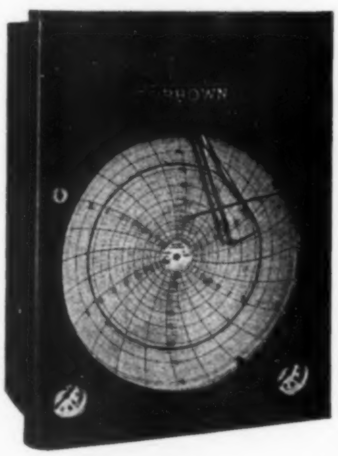
Recently released from active duty in the Army Ordnance Department, **Gordon D. Kimpel** has been appointed chemist at the Lovell Manufacturing Co., Erie, Pa.

W. E. Wilson has returned to the architectural metals division, General Bronze Co., Long Island City, N. Y., after several years with the Jessop Steel Co.

James R. Macdonald, formerly assistant professor at West Virginia University, is now associate professor of chemical engineering in charge of metallurgical courses at the University of Denver.



The Secret of Bright Chromium Plating



Brown Thermometer with Air-Operated Control.

This typical chart shows the secret of uniform, bright chromium plating. You can clearly see that the relationship between the cathode current density and the bath temperature determines the quality of the chromium plate. Even small variations of either factor cause burnt, frosty or milky plate.

Current density can be easily adjusted and, once set, remains relatively stable. Temperature, however, the other important factor, is subject to wide variations caused by both internal process reactions and external conditions.

Since the temperature range for bright chromium plating is narrow, precise temperature control is essential.

Brown Thermometers with air control accurately maintain temperatures within the close limits required. Actual installation records show temperatures held within one degree Fahrenheit. Brown Field Engineers have years of accumulated experience and "know-how" in applying instruments to plating processes. Their services are available to you without obligation.

Send for Catalog No. 8904 describing Brown Thermometers with Air Control. THE BROWN INSTRUMENT COMPANY, a division of Minneapolis-Honeywell Regulator Company, 4503 Wayne Avenue, Philadelphia 44, Pa. Offices in all principal cities.

TORONTO, CANADA — LONDON, ENGLAND
STOCKHOLM, SWEDEN — AMSTERDAM, HOLLAND

See The Brown Instrument exhibit—Booth 321, Western Metal Exposition, Oakland, Calif.—March 22-27.

MH BROWN THERMOMETERS
INDICATING . . . RECORDING . . . CONTROLLING

PERSONALS

John S. Green has been appointed sales manager of the Ford-Smith Machine Co., Ltd., Hamilton, Ont. He was formerly a sales representative for William Jessop and Sons, Ltd., Toronto, Canada.

After being discharged from the Navy where he did foundry research work at the Naval Research Laboratory, **J. Robert Kattus** has become associated with Aluminum Industries, Inc., Cincinnati, as a metallurgist.

After four years' service in the Naval Reserve, **C. Robert Derhammer** is working as assistant sales manager at Lakeside Steel Improvement Co., Cleveland.

F. H. Ellinger is now doing metallurgical research work at Los Alamos Scientific Laboratory, Los Alamos, N. M.

United States Steel Corp. announces the appointment of **Robert H. Aborn** as assistant director of the Kearny, N. J., research laboratory. Dr. Aborn has been with the Kearny laboratory since 1930.

Edward J. Foley, formerly superintendent of the metallurgical department of Allis-Chalmers Manufacturing Co., has been appointed principal metallurgist, Fairchild Engine & Airplane Corp., N.E.P.A. Division, Oak Ridge, Tenn.

Robert Olson is now sales engineer for the DoAll Co. covering southwest Michigan and working out of Grand Rapids.

Arthur E. Franks, previously employed by the General Electric Co., Schenectady, has accepted the position of plant metallurgist for the Cinaudagraph Division, Indiana Steel Products Co., Stamford, Conn.

Bruce A. Rogers has been granted a leave of absence from the Bureau of Mines to devote his time during the next few months to writing a popular book on metallurgy.

R. Mears has been appointed manager of the research laboratory, Carnegie-Illinois Steel Corp., Pittsburgh.

O. G. Hudson, Jr., has recently joined the Progressive Welder Co., Detroit, as sales engineer.

Ewan C. MacQueen is now employed in the patent department of the International Nickel Co., New York City, having left Thompson Products Co., Cleveland.

Having been recently discharged from the Army, **Richard W. Reynolds** has returned to the University of Illinois to do postgraduate work and is working at Ingersoll Steel Division of Borg-Warner Corp., Chicago.

Herman Gardner, formerly with the Ford Motor Co. of Canada, has set up a laboratory in Kitchener, Ont., for chemical analyses of various types of industrial matter.

Harry E. Wistrand, after completing work for his master's degree at the University of Alabama, is employed as metallurgist with Inland Steel Co., East Chicago, Ind.

Max Vinstein, formerly research metallurgist at Carnegie-Illinois Steel Corp.'s Gary steel works, has joined the metallurgical staff of Kaiser-Frazer Corp., as machinability engineer.

A new business, Maken Metal Products Corp., Glen Cove, N. Y., has been started by **Charles C. Covucci** for the design and manufacture of aluminum and magnesium alloy products. Mr. Covucci was formerly materials and process engineer for Warren McArthur Corp.

PERSONALS

Brown Instrument Company announces the appointment of **O. B. Pyle** as industrial manager of the Philadelphia branch. Mr. Pyle has been with Brown for 18 years.

E. C. **Kron**, formerly with Battelle Memorial Institute, is now associated with the Doehler-Jarvis Corp. as metallurgist in charge of steel and iron activities. Mr. Kron will make his headquarters at the Toledo, Ohio, plant.

Edwin T. Jackman, formerly Chicago district manager for the Firth-Sterling Steel Co., is now associated with the Charles G. Stevens Co., Chicago, as manager of the bar steel division.

John B. Girdler has been appointed assistant general manager of sales of the Vanadium Corp. of America, New York City. Formerly district sales manager, Mr. Girdler will continue to handle sales in the eastern district.

United States Steel Corp. announces the retirement of **Walter E. Hadley** as manager of Chicago district operations. Mr. Hadley has been associated with U. S. Steel since 1904 and held his last post since 1938.

H. C. Bostwick of Cleveland, who represents the Drever Co., manufacturers of industrial furnaces, has also taken on representation for the Sentry Co., Foxboro, Mass., covering the Cleveland and eastern Ohio territory.

F. Harry Hart, a former Army Air Force inspector, is now engineer at the Allison Division, General Motors Corp., Indianapolis, Ind.

W. L. Mudge, Jr., has accepted an appointment as a research fellow and is doing graduate work at the University of Pennsylvania. He was previously a metallurgist at Radio Corp. of America.

After severing his connection with the Bethlehem Steel Co., **S. L. Scheier** has accepted the position of superintendent of the drop forge department of Columbus Bolt Works Co., Columbus, Ohio.

R. Smoluchowski has been appointed associate professor of metallurgical engineering and member of the staff of the metals research laboratory at the Carnegie Institute of Technology. He was formerly a research physicist with the General Electric laboratory in Schenectady.

PERSONALS

Universal-Cyclops Steel Corp. announces the following assignments to its sales organization: **William T. Allison** to the Hartford, Conn., office; **Walter S. Baker** to the Milwaukee office; **William G. Beadling** to the Cleveland office; **Lorenz W. Rinek** to the Detroit office; and **John L. Stewart** to the Chicago office. All of these men have recently joined or returned to Universal-Cyclops after serving in the armed forces.

H. H. Richardson has been appointed president of Aluminium Laboratories, Ltd., and elected to the board of directors of the Aluminum Co. of Canada, Ltd. He will direct the research laboratories at Arvida and Kingston, Canada, and Banbury, England.

The Davison Chemical Corp. announces the appointment of **Marlin G. Geiger**, formerly vice-president of Westvaco Chlorine Products Co., as executive vice-president, and **Elmer B. Dunkak**, formerly Davison engineering director, as vice-president in charge of engineering.

Harry Korn announces the completion of the Nork Products Co.'s new manufacturing plant in Los Angeles for making precision tools.

F. J. Kohut has resigned as general manager of C. M. Kemp Manufacturing Co., Baltimore, Md.

The Timken Roller Bearing Co. announces the appointment of **Walter G. Hildorf** as chief metallurgical engineer of its western division in Los Angeles. Mr. Hildorf was formerly director of metallurgy at the Canton steel and tube division.

Benjamin F. Kubilius, formerly with General Electric Co., has joined the staff of C. I. Hayes, Inc., Providence, R. I., as metallurgist in charge of development and research work in heat treatment of metals.

William W. Dunnell, Jr., has resigned as chief engineer of Rivett Lathe & Grinder, Inc., to accept reappointment to the engineering staff of the division of industrial cooperation, Massachusetts Institute of Technology, Cambridge, Mass.

Robert R. Rawstron, formerly with the Delisle Machine Co., has accepted the position of superintendent of the Lundeberg Engineering Co., Hartford, Conn.

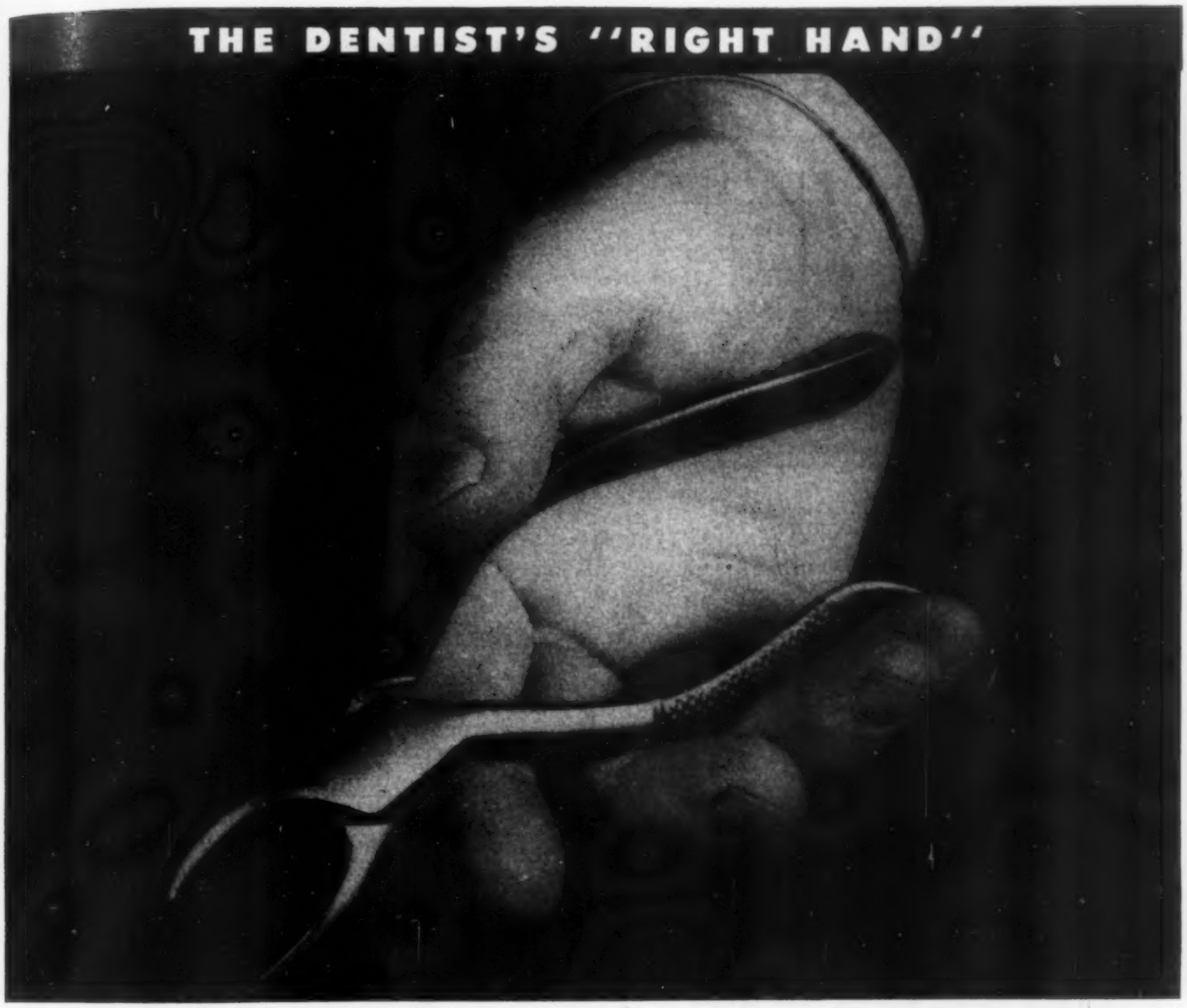
Walter J. Koshuba has resigned as general superintendent and experiment engineer, Solar Aircraft Co., to accept the position of senior metallurgist with the Fairchild Engine and Airplane Corp., Oak Ridge, Tenn.

E. H. Dau has been appointed district sales manager of the Jessop Steel Co. for the Buffalo territory. Mr. Dau was previously special representative for Jessop in the eastern territory.

Alexander L. Feild has been appointed associate director of research laboratories of the American Rolling Mill Co., Middletown, Ohio. Mr. Feild was formerly director of research laboratories, Rustless Iron and Steel Corp.

Joseph T. Ryerson and Son, Inc., announces that **E. F. Wood**, formerly in charge of the firm's Denver office, has been assigned to a new post as manager of the work order department at the Ryerson Los Angeles steel service plant.

W. L. Hawks, who recently completed the cadet training course offered by the Bailey Meter Co., Cleveland, has been assigned a position in the research department of this company.



Heat treating stainless steel was like "pulling teeth"

'til Houghton stepped in!

Ever see these? The dentist keeps them hidden when he says, "Open wide." They've got to be strong to take a continued beating while giving patients punishment, too.

This set is made of stainless steel—always tough to heat treat. They are heated in Houghton's Liquid Heat at 1750° F. for three minutes, quenched in Houghton's No. 2 Soluble Quenching Oil, and drawn back to the desired hardness.

To keep tools free from stain, they are washed in hot water immediately after heat treatment and then immersed in a Houghto-Clean bath made up of 6 to 8 ounces to the gallon of water.

This procedure, worked out between the Houghton Man and the manufacturer, is typical of the individual study which must be given to every heat treating problem. You can depend on Houghton for advice and materials to solve that "puzzler" you may face in conditioning metals for rugged jobs. For a free copy of our new Salt Bath Catalog, write E. F. HOUGHTON & CO., 303 W. Lehigh Avenue, Philadelphia 33, Pa. Offices in all principal cities.

HOUGHTON'S *Liquid* SALT BATHS

PERSONALS

John W. Bizot has recently been transferred from the Reynolds Alloys Co., Sheffield, Ala., where he was metallurgist, to a similar post at Reynolds Metals Co., Brookfield, Ill.

W. Kenneth Badger, formerly at Pratt & Whitney Aircraft Co., has joined the Elliott Co., Jeannette, Pa., as engineer in charge of gas turbine power plants for locomotives.

James R. Ireland, previously with the Western Electric Co., is now metallurgical and magnet engineer for Thomas and Skinner Steel Products Co., Indianapolis, Ind.

Howard N. Farmer, Jr., has joined the staff of the California Institute of Technology and is teaching mechanical engineering.

After three years in the Navy, **Richard P. Weber** has become paint chemist at the Glidden Paint Co., San Francisco.

After receiving his master's degree at the University of Utah, **Curtis L. Graversen** has joined the metallurgical engineering staff of the Montana School of Mines at Butte, Mont.

James G. Green, in partnership with **James J. Crockett**, has organized the Warren Precision Heat Treating Co., Warren, Ohio, to handle commercial heat treating of tools and dies.

William C. Greenleaf has been appointed hot mill metallurgist at the Leechburg, Pa., strip mill of Allegheny Ludlum Steel Corp. Mr. Greenleaf had spent 3½ years in the United States Navy and had been previously employed by the Youngstown Sheet & Tube Co.

H. V. Fairbanks, formerly of Rose Polytechnic Institute, has accepted the position of assistant professor of chemical engineering at West Virginia University. He will have charge of the metallurgical division.

Lt. Francis M. Krill has been assigned by the U. S. Army to the Atomic Energy Commission and is now at the Los Alamos laboratory near Santa Fe as a metallurgist.

A. W. Peterson has joined the staff of the department of mechanical metallurgy of Massachusetts Institute of Technology after resigning from the general plate division, Metals and Controls Corp., Attleboro, Mass.

ADVANCES IN BRITAIN

(Continued from page 413)

Rhodium plating had many important applications in Britain during the war. For electrical contacts it was usually plated over an undercoating of silver. The latter provided protection against corrosion, while the rhodium provided a nontarnishing finish. This should be the housekeeper's friend, when manufacturers of silverware adopt rhodium, and thus save unnumbered hours of polishing.

Special advances have been made in the anodic oxidation of aluminum which yields tough coherent films capable of resistance to atmospheric conditions and also capable of absorbing dyestuffs for attractively colored finishes.

Engineering Applications — The technique of electrodeposition to build up worn, or overmachined surfaces was introduced in Britain during World War I by army repair shops, and has been practiced here since that time. During World War II, more than 60 plants were approved for such purposes, including repair work on new parts undersized in manufacture, the repair and prevention of wear on mobile components, and repair of cracked or leaking castings.

The two metals chiefly deposited were nickel and chromium. Components to the value of many millions of pounds sterling were thus salvaged during the war. Improvements in technique included that of "stopping-off" or restricting the deposit on desired areas on the article by the use of insulating shields.

Miscellaneous — A method for making copper powder by electrodeposition from acid sulphate solution was devised. Electroforming was developed in certain special cases as a method of manufacturing molds or dies for plastics, rubber, and for other articles which proved costly or difficult to machine.

Finally, much research has been carried out on many aspects of materials and techniques involved in the making of metallic joints by soldering, brazing, and welding. This has led to special improvements. Among newer methods of jointing may be included pressure or recrystallization welding.

As will have been seen the experience gained in nonferrous metallurgy during the war years was very considerable, and many of the widespread advances will be of value to postwar technology.

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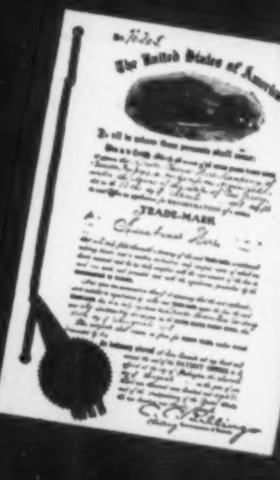

Heat and Corrosion-Resistant Alloy

FROM TIME TO TIME, a product is developed which—by virtue of its originality, overall superiority and general acceptance—meets with instantaneous and lasting success. In so doing, it establishes itself as the standard of quality by which all other similar products are judged.

In industry, an outstanding example of this is NICHROME.

NICHROME is a nickel-chromium heat and corrosion-resistant alloy which is made *only* by *Driver-Harris Co*. Further, it is a *trade mark*, officially registered by the U.S. Patent Office on August 11, 1908 more than thirty-eight years ago. Its leadership in the heat and corrosion-resistant alloy field brilliantly reflects the highly specialized knowledge of technical processes and precise metallurgical controls which have made possible Driver-Harris' outstanding alloy developments for more than 47 years.

Although there are several* excellent nickel-chromium alloy combinations, there is only one NICHROME—and it is made only by the Driver-Harris Co.

Remember this when next you buy a heat and corrosion-resistant alloy. Be sure your supplier understands that you want the *genuine* NICHROME made only by Driver-Harris, for no other company manufactures NICHROME.

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GERMAN BASIC BESSEMER STEELS*

UP TO 10% of the total basic bessemer production in wartime Germany was H.P.N. (initials from "Hamborn, low Phosphorus, low Nitrogen steel"), which is similar to the ordinary basic bessemer steel but has lower phosphorus and nitrogen content than normal. Substantial tonnages have been made in Belgium and Luxembourg, not by the special German process but by careful selection of heats.

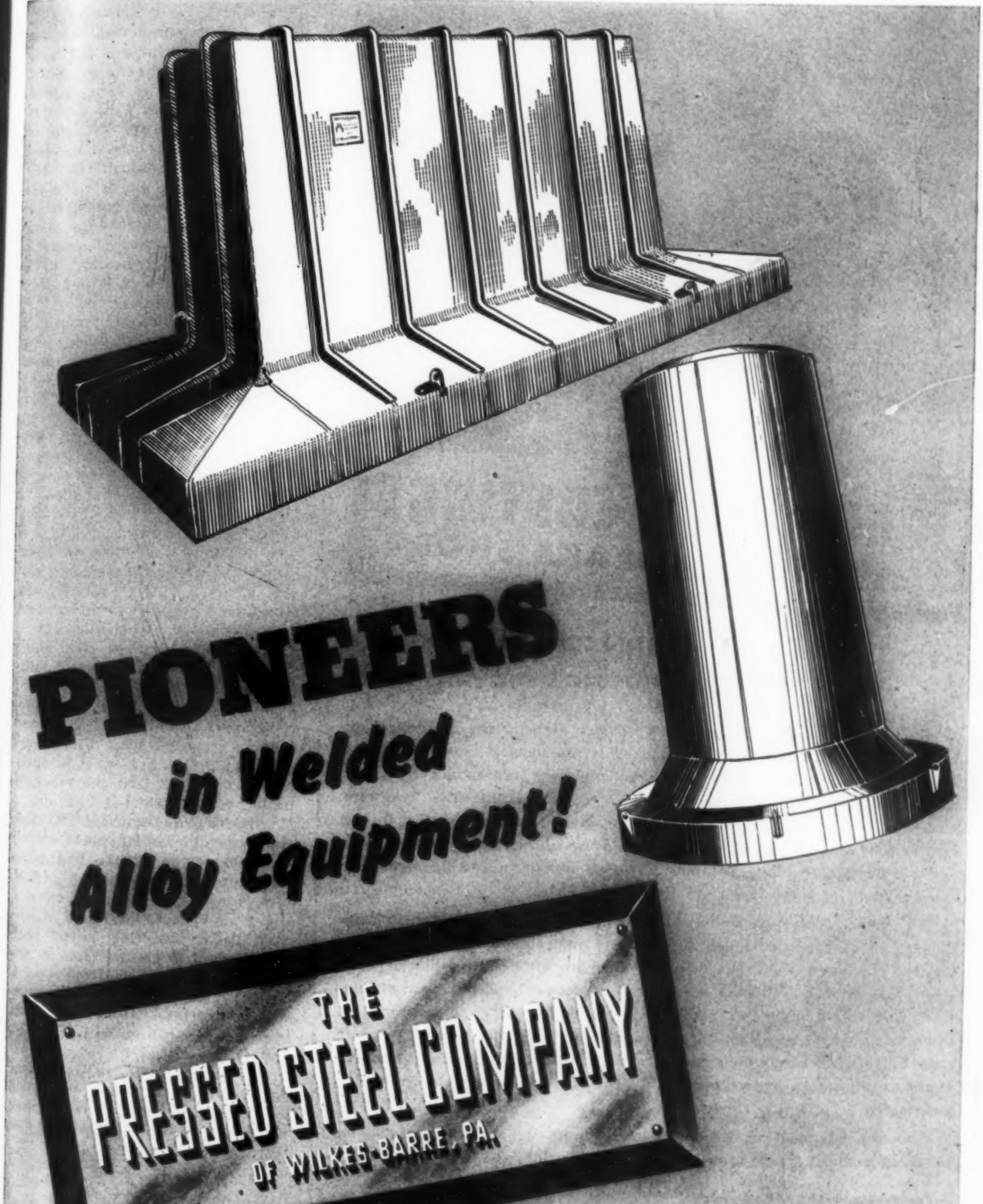
The German process involves reduction of the phosphorus content by lime additions and decrease of the nitrogen by a vigorous carbon boil, along with careful control of temperature and bath depth. For example, a charge of only 30 tons is used in a 40-ton converter. The metal is blown as usual for 8 to 9 min. The vessel is then turned down and 425 to 1055 lb. of iron ore with about 740 lb. of lime added. (Theoretically, any type of iron ore can be used but practically ores of the Minette sort are not used because of their low iron content, high carbon dioxide and cooling effect.) The steel is then finished with ferromanganese. The process requires no special equipment and no more care than is necessary for ordinary low-carbon steel. The time per heat is a little longer than usual but the yield per ton of pig iron is slightly higher. Belgian steelmakers claim their normal practice results in low nitrogen because of the different shape of the converter.

A typical analysis of H.P.N. is 0.04% C, 0.28% Mn, 0.025% S, 0.037% P, 0.009% N. This steel is designated H.P.N. 8, 12, 16 and 24, depending on the nitrogen content. (The number is twice the nitrogen figure; for instance, H.P.N. 8 contains 0.004% N.) It may be furnished rimming or killed, usually with aluminum. For deep drawing, the best grades are rimming H.P.N. with 0.006 to 0.008% nitrogen. Steel with more than 0.007% nitrogen is never killed.

Tests were made on bars 1.97 x 19.7 in., cold deformed, heated 2

(Continued on page 464)

*Abstracted from "Manufacture of H.P.N. Steel in Belgium, Luxembourg and Germany", by T. P. Colclough and J. Simpson. Report No. 345 of the Office of the Publication Board, Department of Commerce, on "Steelmaking in Belgium and Luxembourg During German Occupation".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BASIC BESSEMER

(Continued from page 462)

hr. at 480° F. and then bent 180°, notched and unnotched. It was concluded that rimming H.P.N. is equal to openhearth and better than killed H.P.N. Various comparative bend tests were made on steel with a tensile strength of 58,000 to 71,000 psi. in the as-rolled condition, using test pieces 7.87x 3.94x0.47 in. In the first test the pieces were bent 90°, aged 2 hr. at 480° F. and straightened by static pressure. The order of response was: rimming openhearth, H.P.N. 16, H.P.N. 22, H.P.N. killed with 0.44 lb. aluminum per ton, H.P.N. killed with 0.66 lb. aluminum per ton, basic bessemer killed with 0.44 lb. aluminum per ton, basic bessemer killed with 0.66 lb. aluminum per ton, rimming basic bessemer, and rimming basic bessemer with high nitrogen. The tests were then repeated with the test pieces straightened by hammer blows. Here H.P.N. 16 was better than the openhearth steel. One of the rimming basic bessemer steels gave good results but all the other steels failed. Specimens were next bent 60°, aged 2 hr. at 480° F. and straightened with a drop hammer. The openhearth steel, killed H.P.N. and the basic bessemer steel killed with 0.44 lb. aluminum were satisfactory; the rimming H.P.N. nearly held but the rimming basic bessemer broke at the first or second blow. It seems that killed and rimming H.P.N. are equal to openhearth steel but that the rimming basic bessemer steel is inferior.

Impact tests indicated that both rimming openhearth and killed basic bessemer steels had some advantages over rimming H.P.N. Low-temperature tests indicated a slight superiority of killed H.P.N. over basic bessemer killed with 0.44 lb. aluminum per ton in the as-rolled and normalized conditions but the two steels are practically equivalent if the basic bessemer is killed with 0.66 lb. aluminum per ton.

H.P.N. has been used to replace openhearth steel satisfactorily in many applications. It is supplied for telegraph wire, forging ingots, ship plates, hard steels up to 128,000 psi. tensile strength, screws, drawn and extruded tubes. Rimming H.P.N. is intermediate between rimming openhearth and basic bessemer and is undoubtedly superior to ordinary German basic bessemer steel.

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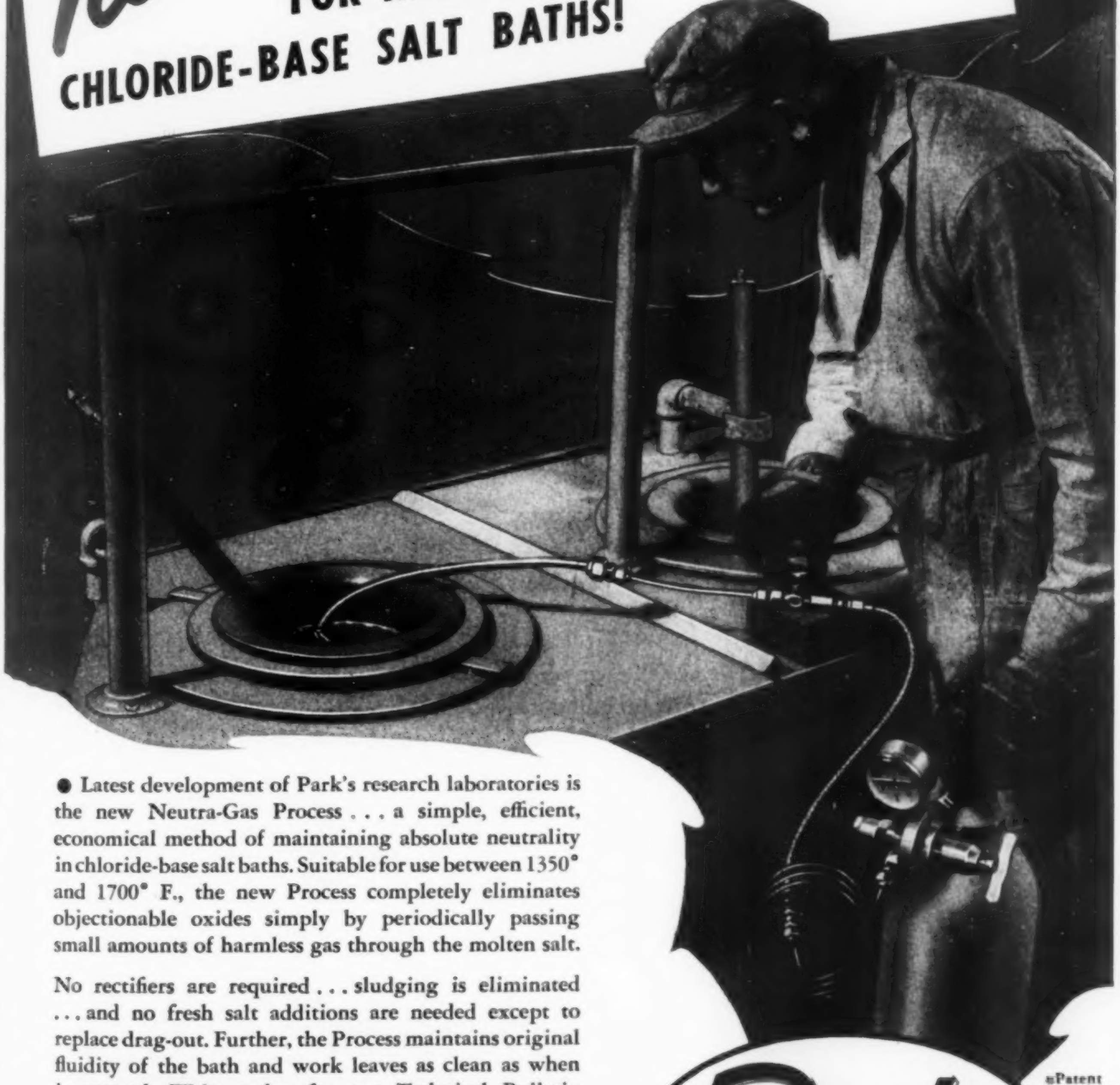

● Latest development of Park's research laboratories is the new Neutra-Gas Process . . . a simple, efficient, economical method of maintaining absolute neutrality in chloride-base salt baths. Suitable for use between 1350° and 1700° F., the new Process completely eliminates objectionable oxides simply by periodically passing small amounts of harmless gas through the molten salt.

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HIGH TENSILE CAST IRONS*

IN ENGLAND, during the past 25 years, the technique of iron founding has altered very considerably. Until World War I cast irons with a tensile strength of 35,000 to 40,000 psi. were exceptionally good. Today material testing 65,000 psi. or higher is commercially available, and the foundry industry is able to furnish a variety of types to meet special requirements such as heat, corrosion and wear resistance. The techniques of melting, molding and casting have been greatly improved, and many problems connected with continuous casting in green sand and permanent molds have been overcome.

The research department of the British Cast Iron Assoc. has been carrying on an investigation for many years to learn how molten iron crystallizes, to determine the influence of various ingredients and to find out why things happen as they do. In 1936, a method of producing fine graphite structure in titaniferous iron was published. Research has continued and now we are able to produce in the laboratory hematite pig iron (low phosphorus and sulphur, silicon about 2.50%) castings with a tensile strength of 45,000 to 65,000 psi. The exact process is still held confidential among the members.

The reason for this superior product is that the iron can be cast into the mold with a graphitic structure of nodular or spherical form instead of stringy, elongated flakes. This structure resembles that found in malleable iron after partial annealing. Test bars have 1 to 2% elongation if the irons have high carbon, and a 2 to 3% elongation with lower carbon. A standard 0.875-in. test bar, cast of hematite pig iron with 3.9% C and 2.6% Si, gave in untreated and treated states, respectively, 35,000 and 59,500 psi. tensile strength and 66,000 and 107,000 psi. transverse. Treatment increased shock resistance from 13 to 47 ft-lb. and Brinell hardness from 185 to 215.

One significant feature of the new development is that it is most applicable to the more easily cast irons. While high-strength cast irons have been *(Cont. on p. 468)*

*Abstracted from *The Engineer*, Dec. 20, 1946, page 573. (The presidential address of D. Harold Hartley of the British Cast Iron Research Assoc.)

STRONG IRONS

(Cont. from p. 466) produced consistently, the price of this improved product has been high; they are more difficult to melt and cast, requiring special precautions. The new material may not supplant the older high-duty cast irons, but it will be used as a basis for producing new ones, the properties of which will no longer be determined by flake graphite structure.

Another admirable feature of the treated material is its uniformity of properties from piece to piece. Of 100 bars cast from 4% carbon hematite pig iron, ten were chosen at random and tested. Tensile strength was between 52,300 and 54,300 psi. and Brinell hardness was between 198 and 203. No test bar showed a flaw.

This new development was a result of persistent and thoughtful research over a period of years. It will lead to a new approach to the design of castings and will influence every branch of the industry. New mechanical and heat and corrosion resisting standards will be set, and there will be a new basis for high-duty and special irons.

CASTING ALUMINUM ALLOY INGOTS*

BRITISH investigators for the Wartime Intelligence Objectives Subcommittee report that the plants of the Ruhr producing wrought light alloys were making wide use of "semicontinuous" casting for ingots, slabs and extrusion billets.

For example, the Vereinigte Deutsche Metallwerke produced high tonnage of duralumin and alclad sheet. The metal was poured direct from the furnace through a runner into a water-jacketed collar, placed — at the beginning of the cast — on a dished copper base. The mold itself formed a water jacket, and bottom spraying gave additional directional cooling. As the metal solidified the base was progressively lowered directly into a tank which contained the vertical hydraulic ram; the water level in this tank was kept about 8 in. from the bottom edge of the mold.

(Continued on page 470)

*Abstracted from "Semi-Continuous Casting", *Metal Industry*, Dec. 20, 1946.


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ALUMINUM INGOTS

(Continued from page 468)

When pouring began, the metal flowed into the dished center of the copper base, lifted to within 1.5 in. of the top of the mold. The hydraulic ram was lowered at the rate of about 2.6 in. per min. Over three tons of alloy could be poured in 24 hr., and various sizes of billets and slabs were in production. Eutectic exudation did not occur on the surface of the ingots, and scrap was negligible when casting conditions were carefully controlled. Casting temperature for duralumin was 1325° F.

A slightly different system was used by the Vereinigte Leichtmetallwerke. Three billets were cast at the same time. Each round die or mold was water cooled and water was sprayed continuously on the billets as they emerged, through an annular gap at the lower inner edge of the die. When casting slabs for rolling, spraying was done through holes in the bottom. Metal was poured from the furnace into a "banjo", from the end of which the metal ran into a star-shaped runner distributing metal to the three dies.

When pouring began, the ram was within a half inch of the top of the mold. Mold and casting block were constructed of an aluminum-base alloy. The bottom block was not fastened to the ram head but was carefully adjusted before each casting so as to give a 2-in. clearance. For rolling slabs, the bottom block was hollowed in the center to receive metal first, and in this way prevent internal cracks. Casting temperature for duralumin was from 1255 to 1275° F. Usual slabs were 6x22x48 in.

A "sliding-face" mold was the patented method employed by Durener Metallwerke A.G. This molding machine had a very long water-cooled die, standing on end, that could be lowered gradually into a pit. Metal was poured through a slit in the side of the mold opposite the hinge, as shown in the sketch. Water at 85° F. and 15 to 30 psi. pressure flowed in the top of the copper-plated mold and out through the bottom. The copper castings alongside the fixed pouring basin were channeled with water passages so the metal was promptly chilled just below the pouring gate; thus there was no leakage through the channel when

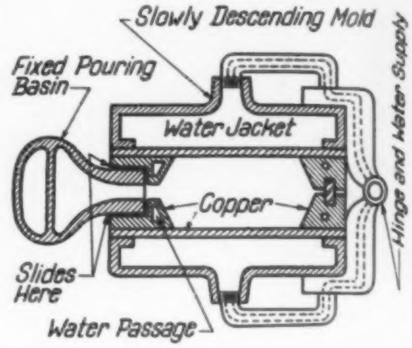
(Continued on page 472)

ALUMINUM INGOTS

(Starts on page 468)

the mold and its gradually solidifying contents were lowered into the pit.

The metal was transferred from the furnace to the mold in an electrically heated ladle and poured into the die through a small banjo with a dross dam. The whole length of the die was out of the pit when pouring began, and was



slowly lowered into the pit during the pouring process. Metal could in this way be poured into the mold without creating a ripple. A heated lid (300° F.) was finally placed on top of the die.

The advantages claimed for this method are as follows: Because the metal does not fall, oxidation is almost completely prevented, and therefore inclusions are reduced to a minimum. Since the metal is not directly quenched in water, the internal stresses are lower than in the direct chill process. An excellent surface can be produced; no metal is lost in a scalping operation. A very fine grain structure is produced.

At Durener Metallwerke the speed for casting duralumin was 5.25 in. per min. for rolling slabs 19x5.5x78.5 in. Casting temperatures were 1275 to 1295° F.

BEHAVIOR OF CUPOLA CHARGE

IN THE LAST ISSUE of the *Proceedings* of the Institute of British Foundrymen (1944-45, Vol. 38) is a remarkable paper about the foundry cupola. The authors, N. E. Rambush and G. B. Taylor, have used a new method of investigating the behavior of charge as it settles and melts, in order to answer the following questions:

(Continued on page 474)

CUPOLA CHARGE

(Continued from page 472)

1. In which place does steel scrap begin to be carburized?

2. What is the degree of carburization before such steel is completely molten?

3. What is the physical state of the steel (liquid, pasty or solid) when carburization takes place?

4. Does the steel pick up sulphur from the coke of the charge?

5. Do the pieces of coke alter in size as the charges descend?

6. Is there any difference between bed coke above and below the tuyeres?

7. Do the pieces of metal arrive at the melting zone in the same position relative to each other as originally charged?

8. What is the location and shape of the melting zone?

The method employed seems to be quite new; the combustion and metallurgical reactions in the cupola are speedily stopped when the top of charge is at the desired level. In order to stop the reactions, the blast was shut off and the whole working charge was quenched with water poured in through the charging door. Complete cooling required less than 40 min. (until water began to run out of the bottom).

Samples from the different parts of the stack were then removed for examination. The metallic burden consisted of 30% pig iron, 60% scrap iron, 10% steel. Coke and limestone amounted to about 18% and 5% of the metal, respectively. The steel scrap was composed of flat bar stock with uniform carbon content (0.20 to 0.23%). The diameter of the cupola was 42 in.; it contained 10 charges of metal and coke when full to the charging sill.

The lining was accurately dimensioned in order to know the extent and location of the wear.

The results of the test may be summarized as follows:

1. Carbon is absorbed on the surface of the steel during its descent in the cupola. The penetration of carbon depends on its position in the charge; it is highest in scrap located near the lining and gradually decreases toward the center. For instance, the increase of the carbon content was traces to 0.36% for drillings from the steel test pieces placed in the center of the charge; traces to 0.63% for the drillings from the pieces placed in the outside of the charge. *(Continued on page 476)*

CUPOLA CHARGE

(Starts on page 472)

2. However carefully the charge materials are placed in the cupola, their original relative position is not maintained during the descent of the charge.

3. Shape and size of the metallic pieces are important factors governing their manner of descent. When different qualities of molten iron must be obtained during the day's heat, the dilution caused by the above factors is very important.

4. Some metallic constituents of the charge cannot be melted completely until they have descended into the coke to a considerable depth.

5. The coke (both bed and charge) is progressively reduced in size as it goes from top to bottom of the shaft.

6. The weight of coke in different heights of the cupola is increased from top to coke bed.

7. The reduction in coke size is not uniform across a horizontal plane. The coke against the lining is almost unaffected and the coke in the center is consumed most. The coke remaining below the tuyere level is the most reduced in size, due to intermittent exposure to direct burning.

8. The slag bridge formed above the tuyere level alters the line of flow of materials through the cupola.

9. Carburization of the steel pieces is slight and variable in the solid state, but as soon as melting commences, the carbon rapidly picks up. Carburization is chiefly on the surface; the center of each piece remains practically unaltered. The highest increase in carbon content found (in a solidified metal droplet) was lower than 1%.

10. The sulphur content increases rapidly on the surface of the steel shortly after its introduction into the cupola. It seems that, on descending, some of the sulphur picked up is given off again.

Some new ideas on carbon pickup were advanced during the discussion of this paper. The American metallurgist, John W. Bolton, says that cast iron should melt at a higher level than steel, and if the burden contains only 10% steel, the hot pieces of steel would be continuously washed by drops of molten cast iron. Samples of partly melted steel have shown traces of steadite in the microstructure near the surface, which confirms that some carbon came from contact with cast iron.